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Supply and Irrigation Paper No. 142 Series O, Underground Waters, 45

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE

LOGY OF SAN BERNARDINO VALLEY, CALIFORNIA

BY

WALTER C. MENDENHALL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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Water-Supply and Irrigation Paper No. 142 Series O, Underground Waters, 45

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Los Angeles, Cal., February 16, 1905.

SIR: I transmit herewith the manuscript of a report on the hydrology of the San Bernardino Valley, California, and recommend that it be published as a water-supply paper. This report has been prepared by Mr. W. C. Mendenhall, geologist, under the general direction of Mr. N. H. Darton. It is one of a series of reports on the underground waters of the valley of southern California.

In this valley, where irrigation practice has attained a high degree of perfection, the underground waters are of very great importance, two-thirds of the irrigated acreage being dependent upon them either wholly or in part.

In this paper those phases of the geology which throw light upon the amount, distribution, and movements of these waters are described, and the effects of development and drought in bringing about those changes in water levels which have taken place in recent years are discussed.

The author has had constantly in mind, in the preparation of the paper, the needs of the practical irrigator and the questions which must arise in disputes concerning title to percolating waters.

Very respectfully,

F. H. NEWELL, *Chief Engineer.*

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

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Director United States Geological Survey.

HYDROLOGY OF SAN BERNARDINO VALLEY, CALIFORNIA.

By Walter C. Mendenhall.

INTRODUCTION.

GEOGRAPHIC SITUATION.

The San Bernardino basin lies near the eastern end of the valley of southern California. Under the latter term is included that general lowland area which is definitely limited on the north by the San Gabriel and San Bernardino ranges and on the east by the latter range and the San Jacinto group, but whose southern boundary is irregular and difficult to define. In this direction there is an interdigitation of ridges and valleys as the Sierra Madre Range of San Diego County dies out toward the north. The more or less indefinite heights that represent its extension in this direction are separated by lowlands, which in turn are to be regarded as southwest lobes of the well-defined east-west valley that lies along the base of the San Gabriel Range.

Toward the west this greater valley opens directly to the Pacific, without the intervention of any extensive heights. The Santa Ana Mountains and the San Jose Hills project well into it from the southeast, at a distance of about 25 miles from the Pacific shore line, in the vicinity of Lordsburg, and reduce its width at this point to but a few miles. The San Gabriel basin and the coastal plain, separated by the low Los Angeles and Puente hills, lie west of this ridge. East of it are the Cucamonga and Chino plains, the Riverside basin, the numerous more or less isolated valleys of the upper San Jacinto drainage area, and the San Bernardino basin, which together form an interior subdivision of the greater valley. The San Bernardino basin is the northeastern part of this interior subdivision, and from the point of view of water supply is most important. It is separated on the east and south from the adjacent lowlands by the Crafton Hills, the ridge known as the Badlands, and the Jurupa Mountains. Toward the west it opens directly into the wide Cucamonga plains. It lies wholly within the valley portion of San Bernardino County and forms a part of the drainage basin of Santa Ana River, all of the streams which flow down

into it from the San Bernardino and San Gabriel mountains being tributaries of this, the most important stream in southern California.

SETTLEMENT.

When in 1851 the first band of Mormon immigrants, led by Captain Hunt, descended through Cajon Pass into San Bernardino Valley, after a journey of months across the parched deserts from Salt Lake, the abundant springs of pure water and the living streams in the great cienaga must have appealed to them with a force which was greatly increased by the vivid memory of the loss of their companions by thirst in Death Valley but a short time before. It is not a matter of wonder that they decided that their wanderings should cease here and that forthwith they began the building of homes, in which they hoped to spend the rest of their lives.

As early as 1810 a mission settlement had been made at Politana, near what is now Bunker Hill, and somewhat later another of more importance and greater permanence was established at old San Bernardino, on the south side of Santa Ana River. Politana was destroyed by the Indians and abandoned soon after its foundation, but the San Bernardino branch mission flourished, and under the direction of the church fathers in charge there the Mill Creek zanja, the oldest irrigation ditch in the valley, was constructed between 1820 and 1830. When the missions were secularized by command of the Mexican Government in 1833, and their lands distributed to Mexican citizens by large grants, the San Bernardino rancho, which included nearly all of the cultivable lands of the valley, fell to members of the Lugo family, and from them it was purchased by the Mormon settlers in 1851 for $7,500.

DEVELOPMENT OF IRRIGATION.

When the Mormons came into possession, the Mill Creek zanja at old San Bernardino was the only irrigating work in this part of California. The wide area of moist lands above Colton, the limited numbers, the simple needs, and the pastoral habits of the first settlers, all combined to reduce the necessity for irrigation, so that the first ditch of their own building was not constructed until 1854. With this beginning, other small ditches were dug in the middle of the valley as the population slowly increased and the irrigated areas were gradually extended, but extensive projects were not undertaken until work was begun upon the first Riverside canal by a New England colony, the Silk Center Association, in 1870. By 1876 both the upper and lower Riverside canals had been completed, and thereafter a constantly increasing acreage was brought under cultivation by the water furnished by them, until in 1882 4,300 acres were reported as supplied by these systems, which at that time depended upon the flowing waters of Warm Creek and Santa Ana River.

During this period the waters from other streams tributary to San Bernardino Valley were diverted and utilized upon the available lands. City Creek water had at first been applied only to the lower lands, to which it could be most easily conducted; but in 1874 a canal was constructed by which it was taken to the "bench" lands in the vicinity of what is now Highlands. The superior value of the bench lands even at this early date was rapidly coming to be recognized.

The Highlands ditch, by which the waters of Santa Ana River were first taken out upon the East Highlands mesa, was built in 1881 and 1882.

In 1883 the construction of the Bear Valley dam was begun, and with its completion in 1884 the reclamation of the valuable citrus lands of the Redlands mesa was accomplished. The success of this project was marred by bad financiering and by a serious overestimate of the amount of water which it would render available, so that although it brought into the productive zone a large acreage of fertile lands which were useless before its completion, these positive gains were accompanied by serious losses.

The tendency constantly observable throughout this period was to extend cultivation to higher ground. The first canals had served only the lowest lands adjacent to the river bottoms; but these lands, subject as they were to frost, proved to be not so well adapted to the valuable citrus fruits as the warmer benches. Encouraged by the success of the earlier projects and recognizing the growing value of the mesas, Matthew Gage, in 1885, undertook the construction of a higher canal from which it was proposed to irrigate a belt of the Riverside mesa lying entirely above the older Riverside canal systems. The Gage canal was constructed in sections and was finally completed to its present terminus in 1888. Unlike the other large canals of San Bernardino Valley, it has depended from the first chiefly upon developed underground waters, and the 7,500 acres of splendid citrus lands which it has brought into the productive zone indicate the results that may be accomplished by the use of such waters.

Since the completion of the Gage system other projects have been put through, but development has been less rapid since the early eighties, partly because the available water supplies were generally utilized in the projects which had been developed by that time and partly because the unfavorable commercial conditions prevailing during the early nineties made investors generally much more conservative.

Among the later developments worthy of note are those of the Riverside Highlands Water Company, organized in 1898, whose latest plant for the supply of the higher parts of the old East Riverside district was installed in 1904. The final result of all of this development has been the reclamation of about 54,000 acres in the Redlands, San Bernardino, and *Riverside quadrangles*. Nearly all of this acreage

depends upon the water supply from the San Bernardino Mountains, either utilized directly as it flows from the canyons or recovered later from underground reservoirs.

By tracing in this incomplete review the development of the irrigation projects within the valley from the time when only the low-lying lands within reach of the old Mill Creek zanja, constructed by the Mission fathers, or those in the moist bottoms which needed no artificial watering, or only such as could be given by the simplest of ditches, were utilized, to the later periods when the superior value of the bench lands came gradually to be recognized and costly and carefully designed irrigation works were planned for their redemption, we gain some comprehension of the constantly increasing demand for water and its concurrently increasing value.

The most important single element in bringing about this development has been the growth of the citrus industry since the foundation of the Riverside colony in 1870. The first citrus trees were probably some seedling oranges grown about old San Bernardino rather as ornamental trees than because they were conceived to be of commercial value. Indeed, before the building of the transcontinental railway lines, which gave the fruit a wide market, they could be of but little importance, since local consumption has never been sufficient to provide a profitable market. In the Riverside colony, however, citrus trees were planted early as a commercial venture, and from a modest beginning there, down on the lower lands under the old Riverside canal, the groves have gradually crept up the slopes to the warm, fertile, frostless soils of the mesa (Pl. II, *A*) until now these lands wherever cultivated are producing the best fruits of the district.

The steady increase of acreage under the various systems and the increasing maturity of the groves first planted have called for constant extensions of the irrigating systems. With the increase in acreage there has gone a constant improvement in irrigation practice and in methods of cultivation, so that the amount of water in use for citrus orchards has diminished from 1 miner's inch for each 3 acres to 1 inch for 5 or 6 acres, and many successful horticulturists maintain that even this diminished amount may be reduced not only without harm but with positive benefit to the soils and groves. The improvement in practice which has already taken place means that the amount of water used for irrigation has by no means increased as rapidly as the area cultivated, yet there has been a slow general increase, as the following table will show.

A. RIVERSIDE-HIGHLANDS IRRIGATION DISTRICT.

B. BALDWIN LAKE.

The available measurements of the waters secured from the San Bernardino basin above Colton are as follows:

Quantity of water from San Bernardino basin above Colton, Cal.

Date.	Quantity.	Observer.
	Second-feet.	
September, 1898	144.69	Kingsbury Sanborn.
August, 1899	110.14	Do.
September, 1900	125.6	Do.
September, 1902	120.21	Do.
August and September, 1903	155.25	Do.
August, 1904	143.98	Do.

Some plants have been installed below Colton during this period, and the waters which they have developed have been used to augment those secured above the "dike;" hence the table does not indicate fully the increase.

BIBLIOGRAPHY.

Since irrigation has necessarily been practiced to some extent almost since the first settlements in this valley, the sources of the water have been the subject of more or less study. Usually these studies have been directly connected with individual enterprises and have been confined to small areas. Their results have not been published for general distribution, but, if preserved at all, are to be found in the records of the various irrigation districts and irrigation companies. A few general papers, however, exist upon one or another phase of the water problem. First to be mentioned is the volume on "Irrigation in Southern California," by William Hamilton Hall, State engineer of California, published in 1888. This work includes a history of practically all irrigation projects completed in this part of the State at the time of its publication. Less attention was paid to developments of underground waters than to surface systems, both because the former were not at that time recognized as of such supreme importance as at present, and because the engineering features were the chief object of Mr. Hall's studies. Nevertheless, this volume remains the most complete general account extant of southern California irrigation systems and is invaluable to a student of the history of the water problem in the southern section of the State.

The results of a later and much more thorough study of the water supply, irrigation developments, and irrigation practice in upper San Bernardino Valley have been embodied in a paper entitled "Water Supply of San Bernardino Valley," by J. B. Lippincott. This paper was published in Part IV of the Nineteenth Annual Report of the

United States Geological Survey, and readers are referred to it for details of the organization of companies operating along the northern and eastern edges of this valley, and for descriptions of the engineering features of interest there.

A later paper by Mr. Lippincott, entitled "Development and Application of Water near San Bernardino, Colton, and Riverside, Cal.," has been issued in two parts, as Water-Supply Papers Nos. 59 and 60, of the United States Geological Survey. This paper includes the results of Mr. Lippincott's studies in the lower, western, and southern parts of the basin and the contiguous regions. In it, as in the earlier paper, particular attention is paid to the surface supplies, to engineering features, and to the organization and operation of districts and water-distributing corporations.

Results of measurements of stream flow made by Mr. Lippincott in his capacity of resident hydrographer of the Geological Survey, or by his assistants, have appeared from time to time in the progress reports of the division of hydrography, and these have been assembled with similar data from other parts of California in a volume entitled "California Hydrography," issued by the Geological Survey in 1903, as Water-Supply Paper No. 81. This volume includes the measurements of the year 1902.

The United States Department of Agriculture has issued, as a reprint from its Office of Experiment Stations Bulletin No. 9, a volume entitled "Report of Irrigation Investigations for 1901," which includes a valuable paper by Prof. E. W. Hilgard on the "Subterranean Water Supply of the San Bernardino Valley." Professor Hilgard has conducted investigations in San Bernardino Valley at several periods, and has paid particular attention to the supply of the Gage Canal Company. By cooperating closely with the engineers of this organization he has assembled a body of facts which have unique value in a study of the underground waters, and will have increasing value as they are augmented by accumulating data.

In the same volume is a paper by the late William Irving, engineer of the Gage Canal Company, on the "Duty of Water under the Gage Canal, 1901." This paper is one of a series issued by Mr. Irving, in which the duty is discussed for the years 1899, 1900, and 1901, the earlier papers appearing in Bulletins Nos. 86 and 104 of the Department of Agriculture, Office of Experiment Stations.

In addition to these papers issued by experts from one or another of the departments of our Government, many scattered data upon particular phases of the question of water supply are to be found in the court records, as a part of the the testimony introduced in the numerous suits which have been filed from time to time.

VIEW OF THE

STRICT

RAINFALL.

It is well understood that southern California is a semiarid region. The precipitation varies widely, however, in different localities, being greater on and near the higher mountains and less in the broad expanses of plain.

Rainfall records, Riverside, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Rainfall for season.
1881	.....	.....	.....	.....	.....	.....	0.48	0.25	1.30	0.74	0.03	0.00	2.80
1881-82	0.00	0.00	0.10	0.40	0.25	0.40	1.70	1.40	1.08	.72	.08	.18	6.31
1882-83	.00	.00	.00	.13	.29	.20	.09	.83	.89	.26	.25	.00	2.94
1883-84	.00	.00	.00	.97	.00	2.25	.84	7.94	6.56	1.67	1.99	.52	22.74
1884-85	.00	3.00	.00	.12	.12	2.56	.77	.00	.01	2.15	.24	.00	8.97
1885-86	.00	.00	.00	.02	1.34	.62	2.68	1.38	1.95	1.43	.00	.00	9.42
1886-87	.00	.00	.00	.00	.54	.04	.13	3.30	.02	1.70	.17	.02	5.92
1887-88	.00	.00	.00	.75	.87	.85	4.17	1.05	3.84	.18	.05	.00	11.76
1888-89	.00	.00	.00	.00	2.83	3.37	.87	1.30	5.10	1.83	.25	.00	15.55
1889-90	.00	.00	.09	1.35	1.82	7.80	4.44	1.96	.60	.06	.09	.00	18.21
1890-91	.00	.05	.79	.13	.32	3.21	.13	6.36	.40	1.04	.46	.00	12.89
1891-92	.00	.00	.13	.03	.00	1.29	.00	2.60	1.07	.00	1.32	.00	6.44
1892-93	.00	.00	.00	.29	.28	.94	3.01	1.95	5.71	.24	04	00	12.46
1893-94	.33	.00	1.27	1.08	.67	2.05	.69	33	70	.00	00	00	7.12
1894-95	.00	.26	.20	.05	.00	5.22	6.48	1.09	2.54	.29	26	00	16.39
1895-96	.00	.00	.00	.00	1.25	.24	1.72	00	3.16	.56	58	.00	7.51
1896-97	.02	.23	.00	2.07	1.48	.92	3.38	3.07	62	.03	03	.00	12.85
1897-98	.00	.04	.09	1.67	.02	.95	1.74	12	80	.18	27	.00	5.88
1898-99	.00	.00	.00	.00	.01	1.38	2.09	89	90	.00	.13	.30	5.70
1899-1900	.00	.00	.00	1.03	.57	.41	1.01	.01	.95	.74	1.29	.00	6.01
1900-1901	.00	.00	.00	.28	2.51	.00	2.67	2.74	.12	.00	.54	.00	8.86
1901-2	.00	.00	T.	.80	.12	T.	.90	1.81	2.23	.23	.16	.05	6.30
1902-3	T.	.00	T.	.09	1.09	1.64	.94	1.24	5.22	2.19	.03	.00	12.74
1903-4	T.	T.	.43	.05	.00	.03	.15	1.21	3.22	.58	.08	.....	5.75

Average, 23 seasons, 9.90 inches.

This distribution follows directly from the fact that the mountains are the rainmakers. The valley of southern California opens to the Pacific, and the moisture-laden winds from this great water body pass inland over the valley lands without marked disturbance of their temperature until they are forced up over the surrounding mountain ranges, where they are cooled and the greater part of their moisture is precipitated. This concentration of the rainfall on and near the mountains is partly illustrated by the available records, although these are not complete for mountain stations. The average at Riverside for twenty-three years is 9.90 inches, for thirty-four years at San Bernardino 15.06 inches, and a doubtful record for the ten wet years preceding 1894 at Bear Valley dam is 57.49 inches. Even though the reliability of the last record is doubtful, and since at best it was continued only during a period when the rainfall of this part of the State was 30

per cent above the average, so that a more nearly correct figure may be obtained if it is reduced by one-half, yet with this liberal reduction it is nearly double the valley records, and thus illustrates the much heavier precipitation at the mountain tops.

Rainfall records, Colton, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Rainfall for season.
1877	.....	.....	.....	.....	.....	.....	1.64	T.	1.72	1.00	1.58	0.00	5.94
1877-78	0.00	0.00	0.00	0.07	0.35	1.93	1.94	5.16	1.38	2.99	.71	.00	14.53
1878-79	.00	.00	.00	.24	.30	1.68	1.79	.74	.03	1.75	.10	.08	6.71
1879-80	.00	.00	.00	.13	1.15	2.49	.99	.76	1.05	2.19	.00	.00	8.76
1880-81	.00	.00	.00	.13	.27	2.37	.74	.90	1.39	.28	.00	.00	6.08
1881-82	.00	.00	.00	.28	.38	.00	2.23	1.28	1.51	1.08	.00	.50	7.26
1882-83	.50	.00	.00	.50	.19	.30	.52	1.72	1.00	.45	.75	.00	5.93
1883-84	.00	.00	.00	.60	.00	2.23	1.00	11.38	4.05	2.85	2.90	.32	25.33
1884-85	.00	.25	.00	.25	.12	3.93	1.00	.00	.00	2.08	.22	.00	7.85
1885-86	.00	.00	.00	.00	1.92	.52	2.78	.40	3.54	.50	.00	.00	9.66
1886-87	.00	.00	.00	.00	.80	.00	.21	3.64	.00	1.94	T.	.00	6.59
1887-88	.00	.00	.00	.00	.70	.80	4.89	.42	3.68	.43	.00	.00	10.92
1888-89	.00	.00	.00	.00	2.37	3.26	.86	.88	4.47	1.02	.60	.00	13.46
1889-90	.00	T.	.04	1.59	1.26	7.41	2.94	1.15	.50	.00	.00	.00	14.89
1890-91	.00	.06	.67	.00	.19	2.45	.00	6.48	.25	.80	.90	.00	11.80
1891-92	.00	.00	.00	.00	.00	.87	2.27	3.36	.80	.24	1.44	.00	8.98
1892-93	.00	.00	.00	(.48)	.90	1.45	2.40	2.91	6.64	.16	.00	.00	15.14
1893-94	.30	.00	.00	1.18	.22	1.93	.20	.55	2.00	.10	.50	.00	6.68
1894-95	.00	.00	.45	.15	.00	5.70	6.88	1.01	2.94	1.08	1.05	.00	19.26
1895-96	.00	.00	.00	.00	1.16	.00	1.10	.00	2.91	.25	.38	.00	5.80
1896-97	.00	.10	(.06)	2.28	.94	1.11	3.52	3.96	2.70	.00	.15	.85	15.67
1897-98	.00	.00	.00	2.20	(.66)	.30	1.48	.23	.80	.10	.34	.00	6.11
1898-99	.00	.00	.00	T.	T.	.45	1.57	.45	1.55	.00	.00	T.	4.02
1899-1900	.00	.00	.00	.00	1.96	.55	1.06	.00	.95	1.59	.89	.00	7.00
1900-1901	.00	.00	T.	.32	6.47	.00	3.44	4.28	.08	.00	1.00	.00	15.59
1901-2	.00	.00	.00	1.18	.23	.00	.70	2.77	3.07	2.56	.00	.00	10.51
1902-3	.00	.00	.00	.15	.97	1.66	1.42	1.60	5.51	4.37	.00	.00	15.68
1903-4	.00	.00	.00	.00	.00	.00	.00	1.60	4.40	.82	T.	.....	6.82

Average, 27 seasons, 10.63 inches.

The practical effect of the low rainfall over the valley lands is that only those crops which grow rapidly and mature quickly can be raised successfully without irrigation. Barley and oats for hay and grain are the principal crops successfully cultivated, and during unusually dry periods the grain may fail to mature and even the hay prove only a partial crop. Some vineyards in the sandy lands, an occasional small grove of olive trees, and a few apricots are also cultivated without the artificial application of water, but much the greater portion of the acreage cultivated, and all of the more valuable lands, are under irrigation.

VIEW OF EAST RIVERSIDE

TA ANA VALLEY.

Rainfall records, Redlands, Cal.

ar.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Rainfall for season.
.....	.....	.....	.....	.....	.....	.....	0.68	1.47	5.70	0.99	0.58	0.00	9.42
.....	0.00	0.28	0.31	1.50	0.52	13.72	4.69	3.03	.89	.16	.68	.00	25.78
.....	.00	2.16	.88	.29	.00	3.02	.00	9.28	1.19	.91	1.10	.23	19.06
.....	.00	1.63	.97	.00	.00	1.51	.87	4.37	2.06	.13	.00	.00	11.54
.....	.00	.00	.03	.00	.63	1.58	3.02	3.93	7.22	.26	.00	.00	16.67
.....	.21	.00	.69	.95	.50	3.46	1.43	1.04	1.01	.25	.64	.00	10.18
.....	.00	.09	.17	.07	.00	7.38	8.66	1.30	3.29	1.37	.57	.00	22.90
.....	.00	.00	.00	.03	2.03	.52	1.52	.24	3.96	.01	1.14	.06	7.51
.....	.01	.00	.00	1.72	2.07	1.37	5.11	5.83	3.00	.14	.63	.00	21.88
.....	.06	.00	.83	2.38	.16	.70	1.96	.79	.99	.31	2.15	.00	10.33
.....	.10	.00	.00	.04	.22	.62	1.92	.71	1.50	.08	.24	.87	6.30
.....	.00	.04	.05	.65	1.28	.46	1.20	T.	.78	2.03	1.41	.00	7.90
.....	.04	.00	.50	.53	3.88	.00	2.25	3.79	.46	T.	1.62	.04	13.11
.....	.00	.00	.00	.92	.09	T.	1.64	2.58	2.82	.36	.08	.31	8.80
.....	.07	.00	.00	.06	1.40	1.50	1.16	1.41	5.86	3.88	.48	.00	15.82
.....	.00	.21	.54	.06	.00	.00	.29	1.50	4.55	.82	.48	.00	8.45

e, 16 seasons, 13.48 inches.

very condition of aridity is not without compensating advan- It is recognized by soil experts everywhere that arid lands are ally fertile. Abundant rainfall leaches the soils of certain val- soluble fertilizing elements. In the arid regions these soluble nts are retained in the soils, which are correspondingly pro- e. Aridity also means a large proportion of bright, clear days, erefore, where water can be artifically applied to the soils, the f growing conditions. The bench lands about San Bernardino combine these advantages. Their soils are fertile, warm and le as to temperature, free from alkalinity, and where water has pplied to them have become among the most valuable agricul- ands in the United States. Citrus fruits of the better varieties ltivated upon them, practically to the exclusion of other crops.

Rainfall records, San Bernardino, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Rainfall for season.
1870–71	0.00	0.00	0.02	0.09	3.11	0.89	6.91	2.21	0.19	0.34	0.11	0.07	13.9[redacted]
1871–72	.00	.04	.13	.60	.88	3.91	.00	2.20	.37	.79	.06	.06	8.[redacted]
1872–73	.00	.18	.04	.00	1.17	4.40	6.50	1.25	.51	.84	.21	.00	15.1[redacted]
1873–74	.00	1.06	.02	.01	.74	5.73	5.51	8.76	1.08	.48	.42	.00	23.8[redacted]
1874–75	.00	.00	.06	1.82	1.88	2.20	7.20	.15	.22	.07	.05	.00	13.6[redacted]
1875–76	.00	.00	.00	.00	7.50	.02	6.55	1.92	3.41	.44	.03	.03	19.9[redacted]
1876–77	.00	.00	.00	.20	.40	.00	3.50	4.03	.83	.26	.30	.00	9.[redacted]
1877–78	.00	.00	.00	.86	.50	3.95	3.33	6.68	2.57	1.71	.66	.07	20.[redacted]
1878–79	.07	.00	.02	.14	.05	4.70	3.59	1.00	.50	1.20	.24	.03	11.[redacted]
1879–80	.11	.02	.01	.94	3.40	6.50	1.56	1.33	1.45	5.00	.04	.00	20.[redacted]
1880–81	.00	.00	.00	.14	.67	8.80	1.40	.36	1.66	.46	.01	.00	13.[redacted]
1881–82	.00	.00	.00	.80	.27	.50	1.11	2.65	3.30	2.91	.00	.00	11.[redacted]
1882–83	.00	.00	.00	.10	.15	.45	1.60	1.10	2.82	2.95	.00	.00	9.[redacted]
1883–84	.19	.00	.53	.85	.09	2.63	1.63	12.20	9.95	5.68	3.17	.59	37.[redacted]
1884–85	.00	.00	.00	.00	.11	3.75	2.79	.11	.28	1.89	1.69	.19	10.[redacted]
1885–86	.00	.00	.00	.39	4.36	1.20	6.34	2.52	4.18	2.36	.32	.16	21.[redacted]
1886–87	.00	.00	.00	.00	.11	.61	.39	6.44	4.41	1.90	.42	.22	14.[redacted]
1887–88	.11	.04	.09	1.17	2.29	1.91	4.01	3.60	3.41	.58	.52	.03	17.[redacted]
1888–89	.00	.00	.00	.05	4.12	4.64	.93	1.50	6.55	2.05	1.13	.00	20.[redacted]
1889–90	.17	.63	.11	2.30	2.23	10.85	5.44	2.52	.89	.00	.31	.00	25.[redacted]
1890–91	.13	2.16	.88	.58	1.27	3.02	.00	7.78	.06	.53	1.67	.00	18.[redacted]
1891–92	.00	.91	.93	T.	T.	1.67	3.24	3.30	1.75	.37	2.10	.08	14.[redacted]
1892–93	.00	.00	.00	.16	1.02	2.23	4.53	3.37	8.00	.48	.08	.00	19.[redacted]
1893–94	.20	.00	.05	1.05	.30	2.28	1.26	.88	1.15	.40	.56	.00	8.[redacted]
1894–95	.00	.16	.37	.15	.00	7.25	7.39	1.14	3.44	.64	.44	.00	20.[redacted]
1895–96	.00	.00	.00	.00	1.14	.66	2.02	.00	2.92	.37	1.00	.00	8.[redacted]
1896–97	T.	.17	.00	2.10	.98	1.09	3.40	5.40	3.41	.08	.11	.00	16.7[redacted]
1897–98	T.	.00	.13	2.10	.21	.57	2.10	.60	.97	.48	1.08	.00	8.[redacted]
1898–99	.00	.00	.00	.03	.05	.44	2.03	.51	3.22	.07	.19	.95	7.[redacted]
1899–1900	.00	T.	.01	.81	1.47	.84	.92	.00	.92	1.96	1.71	.00	8.[redacted]
1900–1901	.34	.00	.23	.36	6.10	.00	3.48	4.58	.43	.56	1.23	.05	17.[redacted]
1901–2	.00	.27	.07	1.69	.28	.04	1.65	3.02	3.89	.57	.12	.15	11.15
1902–3	.01	.00	.00	.09	1.94	1.96	1.96	1.67	6.47	3.10	.24	.00	17.42
1903–4	.00	.15	.16	.07	.00	.00	.18	2.21	5.34	.80	.16	.00	9.37

Average, 34 years, 15.06 inches.

The average seasonal rainfall at San Bernardino for thirty-four years is 15.06 inches. It is estimated by meteorologists[a] that a record which has been kept for thirty-five years gives an average that is within 2 per cent of the correct final average, so that for practical purposes it may be assumed that this San Bernardino average is final. It is interesting to note that the average for the last eleven seasons, beginning with that of 1893–94, has been but 12.15 inches, nearly 20 per cent less than the general average, while for the ten preceding seasons the average was 20.11 inches, or more than 33⅓ per cent above the general average. The fact that the last decade has been one of

[a] Binnie, Alexander R., The mean or average rainfall and the fluctuations to which it is subject: Proc. Inst. Civ. Eng., vol. 109, 1892, pp. 89–172.

ainfall is very generally recognized, but it is not by any means arly understood that the preceding decade, with which the last

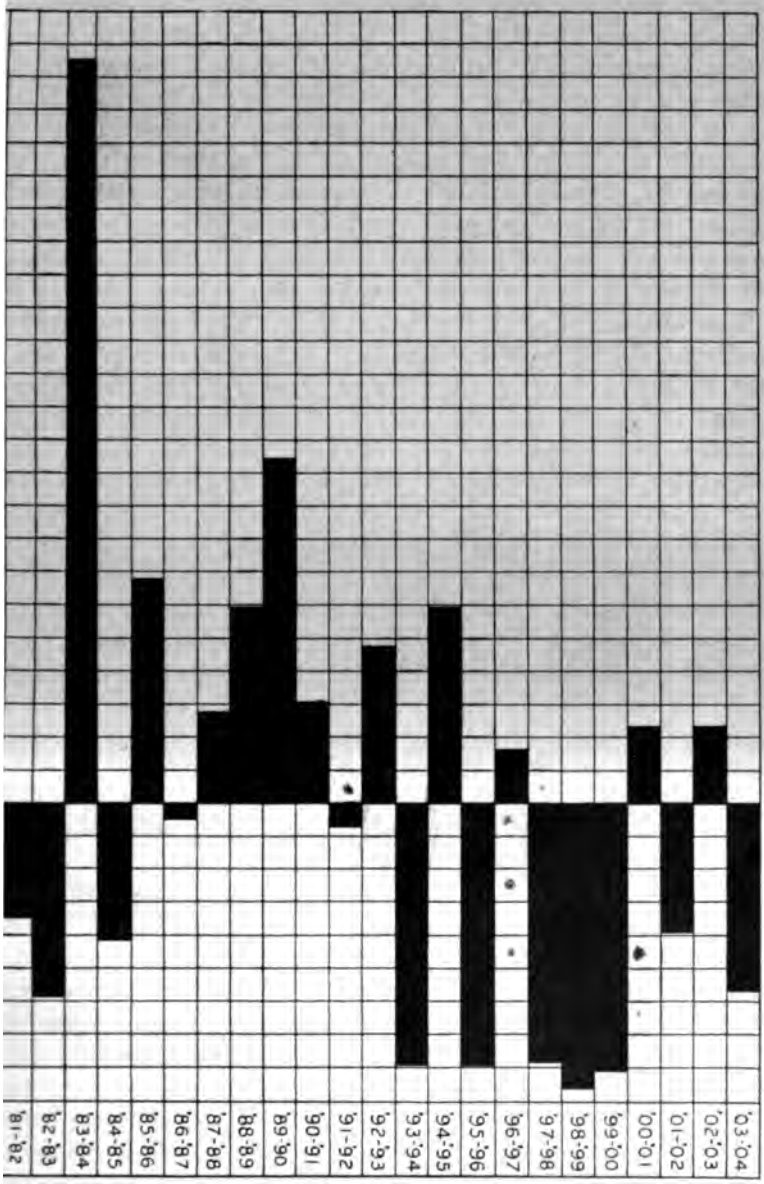


Chart showing variation from average rainfall at San Bernardino, Cal. *a*, Average for 34 years (15.06 inches).

lly compared, was one of great excess. This decade includes enomenal season of 1883–84, with a precipitation of 37.5 inches,

12 inches more than that of any other season in the thirty-four years, and probably much the wettest winter in a half century. The driest season in the record is that of 1898–99, with a rainfall of 7.49 inches, only half of the average, and the driest group of three years is that ending with the winter of 1899–1900, with an average of 8.12 inches.

It is also perhaps not clearly understood that in countries of low rainfall there will be more seasons below the average than above it. The less the average rainfall the greater this preponderance of dry seasons. With an average of 15 inches, as at San Bernardino, the preponderance is not great, there having been eighteen seasons below and sixteen above during the last thirty-four years. At San Diego, with an average of about 9.5 inches, there have been twenty-nine seasons below this average and twenty-five above it during the last fifty-four winters. This condition arises from the fact that where the rainfall is low the occasional very wet winter gives an excess of precipitation equal to or even more than the whole amount of the average, while there are no seasons with an equally great deficiency; hence more than one winter of minimum rainfall is required to balance a winter of maximum. To illustrate, during the season of 1883–84 37.51 inches fell at San Bernardino. The lowest rainfall of which we have record is that of the winter of 1898–99, with a precipitation of 7.49 inches. The first was 22.45 inches above the average, the other but 7.57 inches below, so that nearly three years of this minimum would have to be combined with one of the maximum to give the average. There can not be a deficiency of more than 15.06 inches, while there is no limit mathematically to the excess.

SOILS.

The soils of the upper part of the valley of southern California may, for convenience of discussion, be classed as indigenous and introduced. By the former are meant those which are due to the decay of the underlying or immediately adjacent rock masses; by the latter, those which have been brought by stream action from some distant source.

In the ultimate analysis nearly all valley soils belong to the latter class, since rocks of sedimentary origin themselves represent material which was transported at an earlier time from some more or less distant point. But for our purpose the origin will not be traced so far back. If the soil is derived from an underlying or adjacent rock mass it is classed as indigenous, whether that mass is a late sediment or not.

The soils of the valley bottoms belong in all cases to the derived type. They are the immediate products of the erosional activity of

U. S. GEOLOGICAL SURVEY

REDLANDS AND SAN BERNARDINO AND SAN GORGONIO PEAKS.

the streams, which with the uplifting of the mountain masses began the work of canyon cutting, depositing the material which they removed in this process over the lowlands beyond the canyon mouth.

The gravels and soil, then, in the alluvial fan built about the mouth of any canyon, represent only the rocks that are found within the drainage basin of the stream which flows from it. In the lower area about the junction of two fans the rock types of each are mingled, and well out near the center of the valley, where the various tributaries join, there will be a type due to a mixture of all the contributing varieties.

The soil-producing materials yielded by the canyon of the Santa Ana are largely derived from the dioritic rocks which outcrop almost exclusively in its basin. Mill Creek, in addition to dioritic and schistose rocks, yields a noticeable percentage of sandstone. Farther west schistose and gneissoid elements are contributed by Plunge Creek, City Creek, and East and West Twin creeks, while from the lower part of Devil and Badger canyons there is a considerable addition of limestone and marble.

Lytle Creek, which, because of its relatively large and constant flow, has built out a big alluvial fan at the south base of the San Antonio Mountains, flows throughout its course through schistose rocks, and bowlders of these are numerous in its wash.

San Timoteo Canyon is cut in gravels and clays from Beaumont down to Redlands Junction. It has carried into the lower valley comparatively little material, and that little is fine in comparison with the débris of the great fans in front of the mountain canyons, although it contains bowlders and gravels derived from the older gravel beds which outcrop on either side of the canyon.

This alluvial material, which forms the greater part of the floor of the present valley, is very coarse and absolutely untillable about the mouths of the large canyons, where the lands are in the original desert condition. The vineyards about Grapeland are planted on the rather coarse upper slopes of the Lytle Creek fan, while the Rialto citrus groves are on a lower, finer portion of the same feature. The low bench which lies north of Redlands and extends west from Mentone nearly to Colton is of coarse gravel near its upper portion; fine gravel and sand, on which excellent crops of grapes are produced, midway; and sandy clay and loam farther down, in the vicinity of Idlewild. One group of low sand dunes has formed north and west of Slover Mountain. These generally are untilled, although, since they are low and no longer in motion, it is probable that they could be successfully cultivated if sufficient water were available.

Clays which are often sandy lie in the central part of the valley in the artesian belt, where they are sometimes mixed with vegetable

mold. They represent the lowest and finest phase of the alluvial-fan deposits laid down just back of the dam formed by the Bunker Hill ridge.

Thus it is seen that the introduced soils exhibit great variety in texture and a less marked variation in composition, the latter variant depending upon the origin of the material in one or the other portions of the surrounding mountains and the later admixture of vegetable matter, while the former depends largely upon the distance of the soil particles from their source.

The mesa soils exhibit somewhat less marked differences. Over the high lands south and east of Riverside they are derived largely from the underlying and adjacent diorites, so that here they have many of the characteristics of a granitic sand. Generally they are coarser along the easterly higher parts of this mesa and finer in the lower parts nearer Arlington. Since that part of the mesa which lies north of Terquisquito Arroyo and extends through the east Riverside district to the bluff above Santa Ana River is built up of gravels and alluvium, instead of being floored by the massive diorites of the region farther south, the soil is freer from grit than in the latter locality, being, indeed, a rich loam over much of the area.

The soil of the Redlands bench, including Smiley Heights, Redlands Heights, and the slope south of Crafton, is a clay or loam, sometimes gravelly, derived from the weathering of an old alluvium, which, except in its distribution and probable extent, is not unlike that which the rivers are depositing in the great débris cones to-day. Its material is somewhat finer, clay predominates to a greater degree, and the old weathered red surfaces testify to slower deposition, or perhaps to longer exposure to atmospheric agencies before deposition.

The Highlands and East Highlands benches and that lying between the Mill Creek and Santa Ana canyons furnish similar soils derived from the old alluvial-fan material. That, like the modern alluvium, is somewhat coarser next to the mountains and near the mouths of the greater canyons. But even where coarse it contains a notable admixture of clay, which furnishes a basis for a fertile soil.

The most absorptive soils extensively cultivated are probably the sands of the low river terraces north and northeast of Redlands, and perhaps those least absorptive are the clays of the bottom lands about San Bernardino. Absorptive capacity depends, among other things, upon the coarseness of the soil particles, or, as it has been well expressed, upon the "effective size of grain." Hence the clay and loam soils, whether upon the mesa lands or in the bottoms, require much less water for irrigation than the more open sands and gravelly soils. Another element which is of the utmost importance in determining the amount of water that must be applied in order to mature crops is the character of the subsoil. If this is coarse and open,

readily draining the water from the cultivated surface, the waters brought for irrigation may quickly pass down out of reach of the plant roots. On the other hand, a compact and impervious hardpan holds the waters until they are absorbed by the plants. If bed rock lies just under the soil it may serve the same purpose. An excellent example of the effect of this latter relation is to be found near the eastern end of the Jurupa Mountains. The road from Bloomington to West Riverside runs through a wide valley separating an eastern outlier of this group from the main mass. The soils within this valley are a result of the decay in place of the diorites and schists of the hills. They are not of great depth and the massive and almost impervious rock is just beneath them. A small apricot orchard has been planted in the north end of this pass, about 2½ miles southwest of Bloomington, and although not irrigated it is in a flourishing condition and yields abundant crops. The orchard is young and has been in bearing practically only during the years of light rainfall, which began with the winter of 1897–98. The explanation, it is believed, is to be sought in the fact that the impervious bed rock at this point is so near the surface. The water which accumulates through winter rainfall seeps very slowly over this gently sloping floor, and the slight spring and summer seepage from the surrounding hills and slopes is also held here within reach of the plant roots until the crop is matured. In less favorable localities apricots require irrigation, or without it are uncertain in yield.

WATER SUPPLY.

The ultimate source of all the water to be found in San Bernardino Valley is the rainfall within the drainage basins tributary to it. This statement needs to be clearly made at the beginning of any discussion, because it is constantly stated that some remote point, like Colorado River, or even the Pacific Ocean, may, by a process never clearly explained, supply the bountiful waters found in the San Bernardino cienaga. Aside from the inherent impossibility of such waters rising above their sources, or being filtered free of salt in the case of the Pacific, it is to be remembered that the intervening hills and mountains are much more effective and impenetrable dams than any built by man. The fissures within them are not extensive, and the great faults which mark the more important passes through them are so sealed by the pressures that accompanied their formation as to be nearly, if not quite, as impervious as the unbroken rock.

EFFECT OF FORESTS.

The precipitation which is the source of all the water falls almost exclusively in the winter months, from November to April, inclusive.

Practically all of that which falls upon the flat and porous valley lands is absorbed immediately or returns to the air at once by evaporation. Of the greater amount which falls upon the mountain slopes, a large proportion is absorbed by the soil and humus where vegetation has not been destroyed by fire and the unprotected soil swept from the bare rocks by succeeding storms. This moisture, taken up by the vegetable mold, the soil, and the rock débris, is released slowly during the succeeding months and is the source of the important summer flow of the mountain streams. The denser the vegetable growth and the thicker the soil cover on the mountain slopes the more effective this direct storage of the winter rains and the more uniform the stream flow during the summer months. These facts are brought out by some measurements made for the Bureau of Forestry in the San Bernardino Mountains in 1899 and published in a paper by J. W. Toumey, entitled "The Relation of Forests to Stream Flow." The following extract contains the essence of the paper:

In a careful study of the behavior of the stream flow on several small catchment areas in the San Bernardino Mountains it has been found that the effect of the forest in decreasing surface flow on small catchment basins is enormous, as shown in the following tables, where three well-timbered areas are compared with a nontimbered one:

Precipitation and run-off during December, 1899.

Condition as to cover.	Area of catchment basin.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
	Sq. miles.	*Inches.*	*Acre-feet.*	*Per cent.*
Forested	0.70	19+	36−	3
Do	1.05	19+	73+	6
Do	1.47	19+	70−	6
Nonforested	.53	13−	312+	40

At the beginning of this rainy season, in early December, the soil on all four of these basins was very dry as a result of the long dry season. The accumulation of litter, duff, humus, and soil on the forest-covered catchment areas absorbed 95 per cent of the unusually large precipitation. On the nonforested area only 60 per cent of the precipitation was absorbed, although the rainfall was much less.

Rainfall and run-off during January, February, and March, 1900.

Condition as to cover.	Area of catchment basin.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
	Sq. miles.	*Inches.*	*Acre-feet.*	*Per cent.*
Forested	0.70	24	452+	35
Do	1.05	24	428+	33
Do	1.47	24	557+	43
Nonforested	.53	16	828+	95

The most striking feature of this table, as compared with the previous one, is the uniformly large run-off as compared with the rainfall. This clearly shows the enormous amount of water taken up by a dry soil, either forested or nonforested, as compared with one already nearly filled to saturation. During the three months here noted on the forested basins about three-eighths of the rainfall appeared in the run-off, while on the nonforested area nineteen-twentieths appeared in the run-off.

Rapidity of decrease in run-off after the close of the rainy season.

Condition as to cover.	Area of catchment basin.	Precipitation.	April run-off per square mile.	May run-off per square mile.	June run-off per square mile.
	Sq. miles.	*Inches.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
Forested	0.70	1.6	153—	66—	25—
Do	1.05	1.6	146—	70—	30—
Do	1.47	1.6	166+	74—	30+
Nonforested	.53	1	56+	2—	0

The above table clearly shows the importance of forest in sustaining the flow of mountain streams. The three forested catchment areas, which during December experienced a run-off of but 5 per cent of the heavy precipitation for that month and which during January, February, and March of the following year had a run-off of approximately 37 per cent of the total precipitation, experienced a well-sustained stream flow three months after the close of the rainy season. The nonforested catchment areas, which during December experienced a run-off of 40 per cent of the rainfall and which during the three following months had a run-off of 95 per cent of the precipitation, experienced a run-off in April (per square mile) of less than one-third of that from the forested catchment areas, and in June the flow from the nonforested area had ceased altogether.

In view of these facts, which illustrate conditions of wide application, no policy can be conceived which would be more suicidal than one which would permit the stripping of forests or the destruction of these or the chaparral by fires. The immediate and direct result would be the washing away of the earth and humus by the first winter rains, and thereafter destructive floods in winter and dry stream beds in summer. The opposite policy that of preserving and extending the forest and brush cover—may be expected to tend slowly, and almost imperceptibly perhaps, but none the less surely, toward an equalization of the summer and winter flow of the mountain streams. No public work is deserving of fuller support and more hearty cooperation on the part of the citizens of southern California than this of conservation of the existing plant growth and of forest extension. It is one of the curious anomalies of human nature, but one to which Department workers are well used, that those who have had the work of forest preservation in hand have often had to meet bitter opposition from the very citizens whose vital interests they were at the time protecting.

Before the advent of man in San Bernardino Valley all the waters of the mountain streams, except during periods of exceptional flood, promptly sank when they reached the coarse débris cones at the

mouths of their canyons and continued their journey seaward through the porous sands and gravels with which the valleys are filled. They rose to the surface again only when in their underground passage they reached some impervious obstacle like the Bunker Hill dike above Colton, or the bed-rock obstructions at Riverside Narrows and in the lower canyon of the Santa Ana.

The developments of the last fifty years, however, and especially of the last thirty, have resulted in the appropriation of practically all of the normal flow of these streams for purposes of irrigation. Much the greater part of this diverted stream water is returned to the land within the valley in the process of irrigation, but when thus used and spread out over a large acreage of relatively fine soil a very much larger proportion evaporates directly than when the water entered the coarse gravels at the mouths of canyons previous to its diversion; and another important percentage is absorbed by the growing plants and is transpired through them into the air.

RETURN WATERS.

The percentage of irrigation water which returns to the underground reservoirs must vary greatly in different localities and with varying soils and irrigation customs. The sandy soils of some of the bottom lands are so loose that the water percolates rapidly through them and much of it is beyond the reach of the plant roots before it can be absorbed. In the finer loam and clay soils, especially those underlain by an impervious hardpan which checks the escape downward of irrigation water, probably but a small percentage avoids evaporation and absorption and so returns to the ground water. This will be especially true where the better irrigation methods are practiced and no more water is put upon the soil than is needed.

In view of these variable and uncertain elements which enter into the problem, it becomes impossible to estimate with accuracy the proportion of diverted stream water which again becomes available for use as return water from irrigation. It can only be said that the percentage must vary within wide limits, perhaps such wide limits as 5 and 50 per cent, and that with improvements in irrigation practice it will become constantly less. Nevertheless, in certain favorable situations, it seems to be of considerable importance, and may result in changing an arid section to one with an abundant or even a superabundant supply. Thus, in the western and lower part of the Riverside colony, within a restricted area, ground waters have increased during years past until bogs have formed and drainage ditches have become necessary. Fifty second-feet of water are constantly applied in irrigation to the higher lands which drain in this direction, and in the past, and to a less marked extent at present, there has been overirrigation in a part of the area.

Santa Ana River, between the intake of the lower Riverside canal and the Auburndale Bridge, has been increasing in volume since measurements were first made in 1888. The following table indicates the extent of the increase between Riverside Narrows and the Auburndale Bridge, but as practically all of the water flowing at the first point rises below the intake of the lower Riverside canal, the difference between the earlier and the later measurements there is also to be regarded as due to an increase in the volume of rising ground waters.

Discharge measurements of Santa Ana River.

Date.	Point of measurement.	Discharge.	
		Miner's inches.	*Second-feet.*
1888.			
July 16	Jurupa or Riverside Narrows	505.0	10.10
July 17	do	525.0	10.50
July 17	Auburndale Bridge	728.5	14.57
August 21	Jurupa or Riverside Narrows	425.5	8.51
August 22	Auburndale Bridge	664.5	13.29
September 14	Jurupa or Riverside Narrows	474.0	9.48
September 15	Auburndale Bridge	709.5	14.19
1889.			
August 13	Jurupa or Riverside Narrows	550.0	11.00
August 14	Auburndale Bridge	777.5	15.55
September 27	Jurupa or Riverside Narrows	560.0	11.20
September 28	Auburndale Bridge	832.5	16.65
1890.			
August 12	Jurupa or Riverside Narrows	937.9	18.76
August 13	Auburndale Bridge	1,112.5	22.25
1891.			
September 9	Jurupa or Riverside Narrows	775.0	15.50
September 10	Auburndale Bridge	1,281.5	25.63
1892.			
September 10	Jurupa or Riverside Narrows	1,469.1	29.38
September 11	Auburndale Bridge	2,171.4	43.43
1899.			
September 9	Jurupa or Riverside Narrows	1,984.5	39.69
September 12	Auburndale Bridge	2,991.5	59.83
1900.			
July 27	Jurupa or Riverside Narrows	1,920.5	38.41
July 28	Auburndale Bridge	2,722.0	54.45
1901.			
August 30	Jurupa or Riverside Narrows	1,693.5	33.87
August 27	Auburndale Bridge	2,185.0	43.70

Discharge measurements of Santa Ana River—Continued.

Date.	Point of measurement.	Discharge.	
		Miner's inches.	*Second-feet.*
1902.			
October 10	Jurupa or Riverside Narrows	2,162.5	43.25
September 2	Rincon Bridge [a]	3,750.0	74.90
1903.			
August 25	Jurupa or Riverside Narrows	2,035.0	40.70
August 19	Rincon Bridge [a]	3,000.0	60.00

[a] Measurements are now made at Rincon wagon bridge, instead of at Auburndale Bridge as formerly. Measurements made at these two points, by W. B. Clapp, on September 23, 1903, indicate that the flow at the former point is about one-third more than at the latter.

This rather remarkable increase is usually attributed to return waters from irrigation in the vicinity of Riverside, Pomona, and Ontario, and it is probable that the greater part of it is correctly assigned to this cause, but there is another possibility which deserves to be considered. The decade of excessive rainfall ending in the early nineties thoroughly saturated the gravels near the mountains in this part of the State. Subsurface percolation varies widely in rate, this being dependent upon the coarseness of the material through which the water passes. Rates between zero and 96 feet per day have been measured by Mr. Homer Hamlin[a] in the narrows of Los Angeles River, and rates with lower maxima are reported by Professor Slichter from Mohave River below Victorville and from the Paso de Bartolo. If a rate of 25 feet a day, or less than 2 miles a year, is assumed, the increasing flow of Santa Ana River during the last sixteen years may be due in part to the slow escape to the river of the waters that accumulated in the alluvium near the mountains during the decade of wet years preceding the present dry epoch, since these waters would have to pass through from 10 to 20 miles of gravels between the canyon mouths and the part of the Santa Ana in question. No criteria are known by which we can distinguish between these two possibilities at present. If the Santa Ana shrinks again later during a period when the minimum rainfall of the present decade is due to reach it, we can conclude that its fluctuations are to be attributed to this slow passage of the waters of wet and dry periods through the underground pores. If, on the other hand, its increased flow is maintained or continues to increase, this will prove that it is due to returning irrigation waters.

[a] Hamlin, Homer, Underflow tests in the drainage basin of Los Angeles River: Water-Sup. and Irr. Paper No. 112, 1905, pp. 34–50.

appropriated by that time, led to an extensive use of the under-
nd waters of the artesian belt as a source of water supply. Dur-
he later eighties and the early nineties the great majority of the
of the Gage canal system were put down, and the Riverside
r Company considerably augmented its supply from Warm Creek
he Santa Ana by sinking a number of deep wells within the arte-
belt. The Lytle Creek cienaga was also developed as a source of
stic water by the cities of San Bernardino and Colton, and for
ation water by a number of irrigation districts.
e seemingly unlimited amount available in the great cienaga, and
esistance which it had offered previous to 1897 to the drains upon
ring the preceding decade of rapid development, led to great con-
ce in it and gave many the impression that as a source of water it
ndependent of seasonal variations in precipitation, of diversions
reams tributary to the valley, or of drafts upon its stored supply.
concurrence of the series of years of low rainfall, beginning with
inter of 1897–98, with the gradually increased use of waters devel-
during the preceding decade, soon produced its effect, however,
or some years the artesian area has been shrinking, the flow of wells
n it diminishing, and the water plane without it rapidly falling.
increase of rainfall at once affects water levels, as is shown by the
nal increase of flow from artesian wells during the winter and the
cularly noticeable rise in water levels after the winters of 1900–
and 1902–3. In most cases, however, these improvements in con-
ns do not last through the succeeding dry season because of the
y drafts now being made upon the basin. The general reduction
w and lowering of the water plane, although most clearly recog-

capacity as a storage reservoir, the rapidity with which its supply may be renewed, and the rate at which this supply may be drawn upon depend upon these underground conditions.

ORIGIN OF SAN BERNARDINO BASIN.

A great fault runs northwest and southeast through Cajon and San Gorgonio passes and along the base of the San Bernardino Mountains. In the movement along this fracture a portion of the earth's crust north of the present valley was uplifted and now forms the San Bernardino Mountains, while the valley itself represents a great depressed area south of the fracture.

Another crustal movement, whose beginning at least may well have been contemporaneous with the first, both being very late geologically, resulted in the lifting of a ridge—the formation of an irregular arched wrinkle—extending from the San Jacinto Mountains northwestward along the line of the Badlands, which separate San Timoteo Canyon from San Jacinto Valley. The rocks which were folded into this arch are soft shales and sandstones and gravelly alluvium, like that deposited by the rivers now in San Bernardino Valley. This fold can be traced on the surface as the Bunker Hill dike to a point nearly 2 miles somewhat south of west of San Bernardino. It probably extends even farther in the direction of Lytle Creek Canyon as an underground feature, buried beneath the modern wash, but there is no surface indication of its presence there.

This clay and gravel ridge has been the most effectual of subsurface dams, against which the modern stream wash has accumulated, and behind which the waters percolating seaward through this wash have been stored, the excess rising in springs and flowing over the dam, to sink again in the sands and gravels below.

It is not possible to determine in detail the character of the floor of the San Bernardino basin, but we can gain a conception which is probably correct in its general outlines by a consideration of the nature of the surface whose deformation gave rise to it.

Before the San Bernardino Mountains were uplifted and San Bernardino Valley was formed subaerial erosion had reduced an earlier topography to a condition in which the valleys were wide and generally level and the mountains low, although often steep, because the granitic rocks from which they were carved weather characteristically into steep forms.

Such a surface is now to be found in the triangle at whose vertices are Riverside, Elsinore, and San Jacinto. Other fragments of this old landscape are, it is believed, still preserved in practically the condition in which they existed previous to the deformation in Bear Valley and its continuation about Baldwin Lake (Pl. II, *B*), in Holcomb Valley, in Little Bear Valley, and in other of the areas

now forming some of the higher parts of the San Bernardino Mountains.

The topography of these higher areas, where it has not been altered by modern gorge-producing agencies, consists of broad valleys with ridges of moderate elevation between them and is much like that in the region north of Elsinore. It is believed that these two regions, now so widely separated geographically and in elevation, once formed a continuous surface, and that San Bernardino Valley, between them, was a part of this surface, like the other parts in character and developed with them.

DEPTH OF THE BASIN.

When the series of earth strains which deformed the region came into play, Perris Valley was raised slightly, the San Bernardino Mountains were raised much more, and San Bernardino Valley, between them, sank until parts of its old surface came to occupy a position below sea level. How much below it, it is not possible to tell with any exactness, since the deepest wells bored in the center of the valley do not reach bed rock, and the character of the movement and of the land affected was such that it is difficult to estimate the amount of the displacement. An estimate, which, however, is little more than a guess, may be made by considering the maximum relief preserved upon the old surface and applying the criteria thus obtained to San Bernardino Valley.

The heights about Bear Valley usually do not rise more than 3,000 feet above its level; those surrounding the other flat mountain valleys rarely attain this relief. The Jurupa Mountains stand nearly 3,000 feet higher than bed rock in the neighborhood of Bloomington. The peaks within Perris and San Jacinto valleys are generally less than 2,000 feet above the floors of the surrounding lowlands, where the depth to these is known. On the whole, it seems fair to assume about 3,000 feet as the maximum relief on the old surface.

North of a median line through the San Bernardino basin a range of low bed-rock hills rises through the modern wash. These are believed to be hills inherited, like the Jurupa Mountains, from the predeformation surface. On the supposition that they originally stood at about 3,000 feet above the valley floor, this should now be only 2,000 or 2,500 feet beneath San Bernardino.

By assuming that the average slope of the hills, before their burial under the modern wash, was 1,000 feet to the mile—a supposition which is believed to be sufficiently conservative—and that this slope was continuous from the little bed-rock mound below Del Rosa southwestward to the line of disturbance marked by the Bunker Hill dike—a supposition which seems likely to give a greater depth to bed rock than the true one—we reach the conclusion that the latter lies less than 3,000 feet beneath San Bernardino. Nothing whatever is

known of the details in the buried old topography under the r gravels. Perhaps bed-rock hills exist there which differ from that rise above the wash along the northern edge of the valle in that they are not so hi have been completely c by the modern alluvium. floor of the middle of t ley, extending northwe southeast beneath San E dino, may be relatively s like that of Perris V Whatever its characte rough estimate of 3,000 less from the present sur it is the best that can be with the data at hand. (

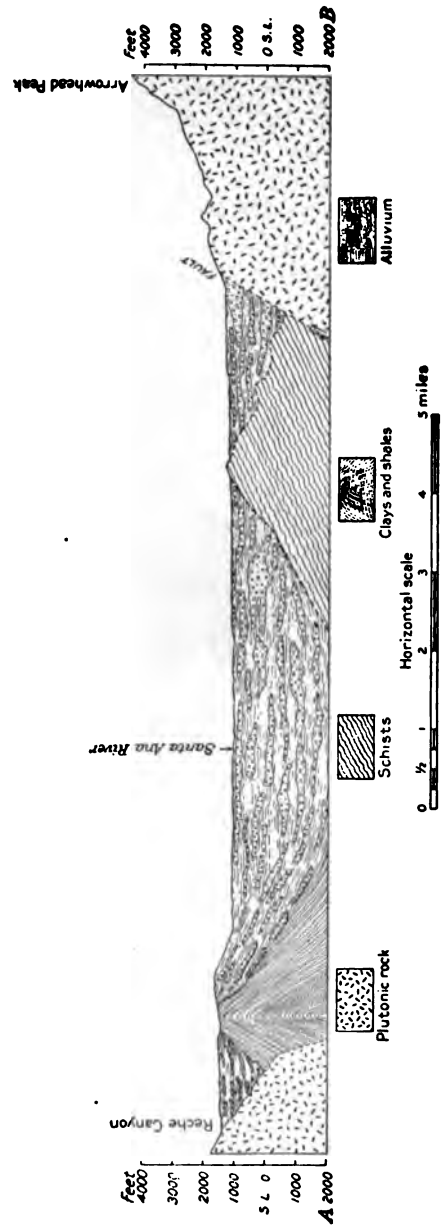


FIG. 2.—Approximate section across San Bernardino Valley along the line A–B, Pl. XII.

GENERAL CLASSES OF R

From the point of view water supply, the rocks upper San Bernardino may be subdivided int general classes—those outcrop everywhere higher mountain regio in many of the hills wit valleys, and the clays an vium which fill the valle derlie most of the fertile and form the greater p the low hills known as th lands between San Jacin upper Santa Ana valley XII shows the distribu the water-bearing and water-bearing rocks region.

The rocks of the first technically include such different varieties as s gneisses, diorites, m quartz-porphyries, sand and conglomerates, bu have the common characteristic of relative compactness, and so and store but little water. The sandstones and conglomerates are included in this class, although belonging to a group of

which in many regions are valuable water bearers, are here so changed by metamorphic processes as to be practically impervious, as is the case with the schistose sandstones of the Jurupa Mountains, or are so broken and so closely folded that their stored water is too small in amount and too doubtful in position to be of value, as is true of the sandstones in the lower part of Mill Creek Canyon, and of those which form a narrow interrupted band along the south foot of the San Bernardino Mountains from East Highlands to Cajon Pass.

The rocks of the second group are the important ones from the point of view of the water user. They consist largely of alluvium, i. e., of sands, gravels, and clays which have been deposited by streams under conditions very similar to those prevailing in San Bernardino Valley to-day, but at their base is a rather widespread series of fine clays and shales, which outcrop along the axis of the Badlands ridge and at various points on the western flanks of the San Jacinto Mountains. These clays carry fresh-water fossils, and their presence indicates that an inland lake whose extent is uncertain existed at least along the southern border of what is now the San Bernardino basin in late Tertiary times, before the earliest of the valuable water-bearing gravels were deposited.

From the fineness of these clays we infer that no very marked relief existed near by at the time of their deposition, because high mountains usually yield coarse detritus, and from the fact that they are bent into sharp folds we know that extensive earth movements have taken place since their deposition. These two facts lead to the belief that the clays are older than the formation of San Bernardino Valley and the San Bernardino Mountains. They were likely deposited in a lake like Bear Lake, but much larger, on the old land surface of rather moderate relief which existed in this part of southern California before the present high mountains came into existence. The topography of that time, it is inferred, was much like that of Perris Valley or of the higher parts of the San Bernardino Mountains at present—that is, there were wide, nearly level valleys, and from these rose ridges or peaks to moderate elevations of a few hundred, or in extreme cases of perhaps a few thousand, feet.

The old lake probably occupied the lowest of the valleys of that time, and within it islands of the granitic or gneissoid bed rock rose, perhaps, as the Box Springs and Lake View mountains now rise above the Perris and San Jacinto plains. It seems probable that these fine deposits extend under at least a part of the San Bernardino cienaga, and that in deep drilling they may be encountered before the granitic bed rock is reached. The beds laid down in the bottom of this lake were too fine to be of value as water bearers, but they furnish a comparatively impervious plane above which the waters accumulate, and

when thrown into a fold across the course of a river, as in the case c the Bunker Hill dike, they force to the surface the waters perc lating through the porous gravels above them, or if an impervio clay layer intervenes between the porous stratum and the surfac they dam back the water so that it is held under pressure and flow when the upper bed is pierced by a drill.

Some time after the deposition of the Badlands clays which hav been described, a series of crustal movements began, which folded th clays and seems to have elevated the San Bernardino and perhap other mountain masses until they stood well above the adjacent valley but were perhaps 2,500 feet lower than at present. It is probabl that at the same time San Bernardino Valley subsided somewhat, s that its rock floor, sheeted over by the lacustrine silts, stood at a lowe elevation than before the movement. At any rate, conditions pr vailed which were much like those of the present. Mountain stream were active; they cut deep canyons and carried the products of thei erosional activity out into the lowlands as they now do. This detritu contained much coarse material, but on the whole was probably nc quite so coarse as the fan material of to-day. It was widely distribute over the lowlands south of the mountains—bowlder beds, sand bed and clays alternating in an uncertain succession until many hundred of feet of alluvium were piled up.

At the close of this epoch in the geographic development of th region, movement was resumed along the lines followed during th earlier period. This movement lifted the San Bernardino Mountain to their present elevation. It raised the earlier deposited alluvi wash into the sloping mesas of Smiley Heights and Redlands Height It probably resulted in the uplift of the Yucaipe bench to a positio somewhat higher than that it had occupied before, and the coars bowlder beds south of San Timoteo Canyon were given the stron northerly dip which they now have. San Bernardino Valley, whic had been depressed in the earlier movement and filled by the erosio following, seems to have again subsided. After this readjustment o the relations of valley and plain, stream activity was renewed, erosio became more active than ever, the present deep canyons were cut, th modern fans were built, and the great alluvial filling, which makes th present surface of San Bernardino Valley and serves as such a valuabl storage reservoir for irrigation and domestic waters, accumulated.

This, in brief, is the history of the geologic and physiographic proc esses which have given us the conditions that now exist and hav resulted in the deposition of the gravels that serve as porous rese voirs and the clays that act as impervious caps that confine the wate under pressure or as equally impervious bottoms to the water basin Such a sketch completed, we are in a position to discuss intelligentl and more minutely the formations which are water bearing, thei

A. LATER ALLUVIUM EXPOSED ALONG THE EDGE OF EAST RIVERSIDE MESA.

B. THE LATER ALLUVIAL FAN ABOUT KENWOOD.

character, distribution, attitudes, and storage capacity, and to draw from the discussion some practical conclusions.

The two important water-bearing formations are, as may readily be inferred from the preceding discussion, the two series of deposits of river wash, which will be spoken of as the earlier and the later alluvium. They are much alike in character, having been deposited under very similar conditions, the differences being that the later alluvium is somewhat coarser than the earlier, has a smaller amount of cement gravel—that is, bowlders embedded in a hard clay, which is often sandy—and has less extensive beds of clay sufficiently pure to be practically impervious to water. Another difference is not in character, but in attitude, the beds of the later alluvium being in just the position in which they were deposited by the rivers that brought their materials from the mountain canyons, while the beds of the earlier alluvium have been disturbed since their deposition—have been given marked dips in one or another direction and have been raised in places until they are now much higher than when deposited. Since water always flows down grade when free, these attitudes are important in their effect upon the circulation of the contained waters.

ALLUVIAL FANS.

Extensive accumulations of coarse or poorly assorted stream-deposited rock fragments, such as constitute alluvial fan material or glacial débris, always indicate that, for some reason, the process of rock disintegration is more rapid than that of removal. In glaciated regions piles of unsorted rock fragments testify to a rapidly accumulated supply concentrated at certain points. In arid regions the very differently arranged masses of débris bear witness, not necessarily to especially rapid accumulation, but to slow removal, because of a dearth of the universal agent of removal, water. Hence, where other conditions, such as character of rocks, height of mountains, etc., are equal, greater aridity is indicated by steeper fans of greater mass and coarser material.

The accumulations take place in glaciated regions because, although the volume of water, which is the great distributing agent, is large, the material is supplied in such quantities that the rivers can not successfully cope with the problem of its removal. It gathers, therefore, and forms the rubble heaps. In the arid regions the same result is attained because of another condition—the smallness of the water supply and the consequent incapacity of the streams. Disintegration may not take place more rapidly than in humid regions, but removal is much slower, hence the spectacle, not rare in the Mohave Desert, of mountains nearly buried under the material which has resulted from their own slow breaking down. With an accession of rainfall the process of removal is accelerated, and the fans formed earlier are gullied and

gradually worn away. It is thus seen that the extent of the alluvial cone accumulations is, within certain restrictions, a measure of aridity. Their presence means limited rainfall; the greater their extent the less the mean annual precipitation where conditions of topography and of rock masses are similar, and the less their extent the greater the precipitation.

The alluvial cones of San Bernardino Valley (Pl. VIII), therefore, testify to the partial aridity of its climate. As these are small in relation to the mountains about whose bases they are found, when compared to those about the bases of the desert ranges, so the valley rainfall is large as compared to the desert rainfall. Yet the striking general fact remains that the most important subterranean water-storage reservoirs of San Bernardino Valley came into existence partly because of the limited rainfall of that region.

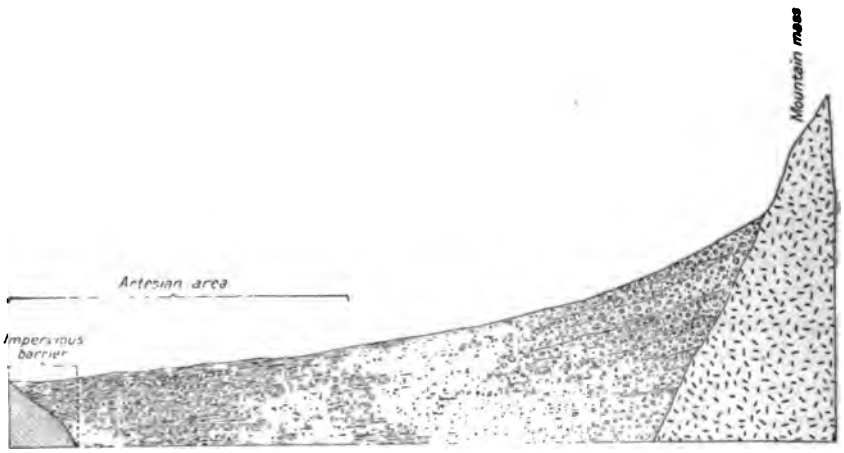


FIG. 3.—Diagrammatic longitudinal section of alluvial fan.

The conditions under which this alluvium has accumulated are, in general terms, simple. Variations in temperature, which cause unequal expansion of the different minerals constituting a rock; freezing of the moisture which has entered rock fissures in the higher mountains; slow solution of some minerals by rain waters, thus releasing others; the forcing apart of rock masses by the roots of different forms of vegetation; and the occasional shattering by earthquake shocks, all help to initiate the disintegration of the rocks of the mountain areas. Once a fragment is loosened, gravity or moving water carries it to a lower point. Thus, in the canyons, quantities of rock débris are constantly accumulating. The normal light flow of the summer season removes only the very fine or the soluble matter. The greater part of the work of removal is accomplished during the brief storms, when torrents rush through these constricted defiles, their carrying capacity

ıg preceding years when the precipitation was light. Or, as one
nel is built up in the manner in which a river builds up its bed
er than the surrounding areas, the course of the stream will shift
ts fan to a lower channel; earlier-formed deposits will be cut
and fine material will be deposited upon coarse, or coarse upon

oderate storms may bring heavy material to the mouth of the can-
and there drop it. A succeeding heavier storm will pick up the
se material laid down in the bed of the stream, move it farther out
lope, cutting into the earlier-deposited burden in the process, and
tablishing a new course which will be filled in its turn.
ter violent storms, during which turbulent waters highly charged
silt spread far and wide over the sands and gravels of the fans,
ı of fine mud is usually found over the river wash; it has been
sited as the muddy flood waters subsided and sank into the sand
gravel. Not all of this fine suspended material was left at the sur-
but much must have been carried down by the sinking waters,
ıally filtered out from them as they percolated through the porous
sits, and left as a clay cement in the interstices between the sand
gravel grains. Much of that muddy film left at the surface may
ter carried down in a similar way by local rains and become a
nt for the coarser material. It is believed that in this way orig-
l a part of the "cement gravel" and "cement sand" so often
ted by drillers and so well exposed in sections of the first allu-
along the sides of San Timoteo Canyon. It makes a stratum
ically as impervious to water as one of pure clay. Others of these
ıt beds probably represent "hardpans," formed just beneath what

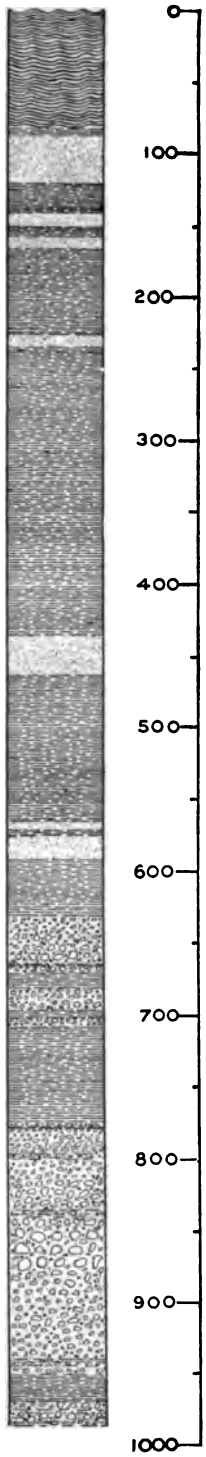


FIG. 4.—Section of the Bucher well.

the material than near it. The general arra is radial, the deposits spreading out fanl the mouth of the canyon, a particular b becoming wider as well as finer at the gr tances, just as the stream itself spreads o greater expanse as it reaches the flatter la distance from the canyon mouths. Cross and local unconformities are abundant. W river deposits are exposed for examination the bluff forming the north edge of the E Highlands mesa (Pl. VI, A), channels filled and gravel are to be seen cutting acros deposits of coarser or finer material, thus "pockets" and explaining fully the discorda observed in the records of adjacent wells (and 9), a water-bearing gravel stratum or a in one being entirely absent in another ne cause in the shifting of channels it has been after deposition.

WELL RECORDS.

Hundreds of wells have been sunk in the the Santa Ana in the last twenty-five yea search for water for domestic purposes or f tion, and the records of these illustrate ab the conditions which have just been describ cavations in the wash north of Redlands sh of roughly stratified sand, gravel, and bow open, pervious material through which the percolate freely. Higher up in the Santa nel the bowlders become large, the fine ma comes smaller in amount and coarser, and t the open spaces greater, although the perc voids is less, because the space occupied large bowlder is free from voids.

Within the limits of the present and th artesian basin the characteristic feature is ence of extensive sheets of clay (figs. 4, 5, They are the finer deposits in this lower p fan, as the sands and fine gravels are the fin its at higher points. While in some of the along the extreme lower edge of the wate lands clay entirely free from grit is enc about the borders it becomes sandy, so tha the driller is in doubt as to whether it shoul sified as a fine sand or as a sandy clay; he we have not continuous sections upon whic

judgment, it is highly probable that upstream the clays merge into fine sand, then into coarse sand, and so represent only the marginal phases of the finer fan deposits. Their porosity must likewise gradually increase upstream from the cienaga, so that, whereas they are impervious caps along the lower borders of the basin, they become open and permit seepage, especially under pressure at higher points.

These clay beds are distributed at various horizons between the surface and the bottoms of the deepest wells drilled, whose depth is about 1,000 feet. The fact that they are often sandy, so that one driller will class a bed as fine sand while another calls the same stratum clay, together with the distinctively irregular character of stream deposits, the local unconformities resulting sometimes in the complete cutting out of a bed at one point and its replacement by another usually coarser, makes the correlation of the minor individual beds through the medium of well records a very uncertain undertaking indeed, and one which it is not possible to carry out unless the wells studied are very near together. In a group of wells within a prescribed area, however, it is usually possible to subdivide the strata into broad units which may be recognized in each well.

This is illustrated in the case of the group of wells belonging chiefly to the Gage Canal Company, and lying from 1 to 2 miles northeast of Loma Linda (fig 5). Throughout this group, originally very important as a source of artesian water, and still yielding a limited supply by natural flow, although many pumps are now installed, a cap of clay 50 to 100 feet thick is first pierced by the drill. Beneath this clay cap is a bed of sand and gravel, often coarse, varying from 100 to 200 feet in thickness. This gravel is saturated, and although the water is not now under sufficient head to flow, it is a satisfactory source from which to pump. This same extensive gravel bed is pierced by two deep wells, designated "P" and "O" of the Gage system on the west bank of the canal just north of Colton avenue, and by an important group of shallow wells east of the extension of D street, San Bernardino. These latter wells belong to the Riverside Water Company and to the Riverside Highlands Company, and since their surface elevation is 50 to 100 feet lower than that of the Gage wells above noted, they flow readily, although the head is not great enough to produce a flow in the less advantageously situated Gage wells.

Below this higher, clearly marked gravel series is a zone of interbedded sands, clays, and gravels about 200 feet thick. The occasional gravel streaks of this series contain water under pressure, so that it flows or rises nearly to the surface. Under this is found a second heavy and apparently rather regular gravel mass in which flowing water is obtained. As it lies 500 to 600 feet beneath the surface, it is tapped by only the deeper wells, and has been pierced by but one or two, so that its extent and regularity are problematical.

In a group of wells lying just west of the Victoria tract and north of the Southern Pacific Railroad, from which the city of Riverside gets

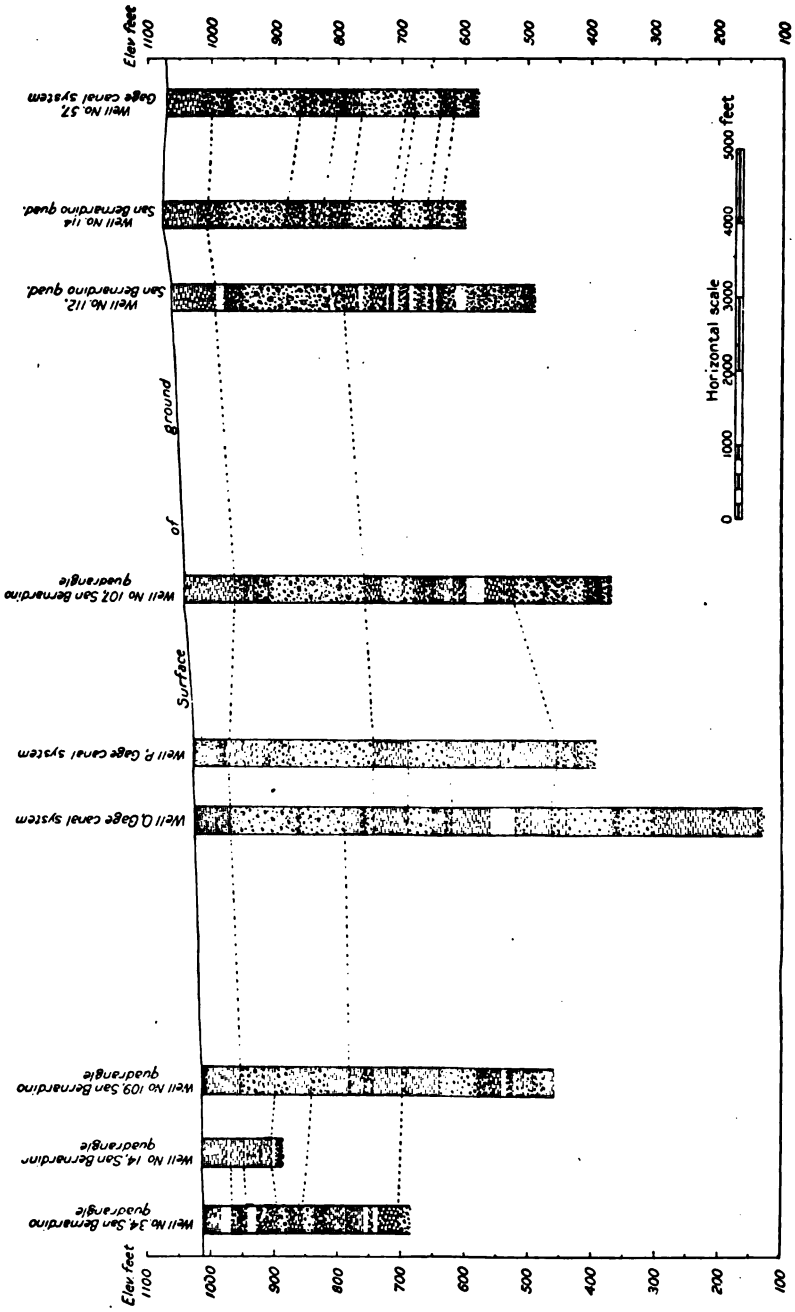


FIG. 5.—Well sections along line A–B, Pl. XII.

its domestic water supply, the upper clay stratum of the Gage wells is recognizable, although sometimes divided into two or more parts by

sandy layers. A bed of coarse water-bearing gravel immediately beneath this occupies the same relative position as the upper heavy bed in the Gage wells, but when penetrated seems to be much thinner. It may be the thin edge of a heavy gravel lens, whose maximum thickness is revealed in the Victoria group. As records are available from only two of these wells which exceed 500 feet in depth, no data exist for an attempt to correlate the deeper strata with those of adjacent groups.

All of the wells which have been considered lie in the lowest part of the San Bernardino cienaga; they therefore exhibit a greater proportion of fine material and a greater regularity in stratification than is to be found in other portions of the basin that lie nearer the mountainous areas and nearer the source of supply of the alluvium.

This is illustrated by a comparison of the records of those wells which lie along Warm Creek from Waterman avenue northeast to Harlem Springs. Many of these wells show a gravel bed immediately beneath the surface soil, although, in the westernmost and deepest, the Waterman avenue well of the Riverside Water Company, the drill passed through 140 feet of clay before entering any extensive gravel body (fig. 6).

Wells but a few hundred feet apart, as, for instance, the first of the new wells drilled by the city of San Bernardino in the Antill tract in 1904, and one of the near-by wells of the Riverside Water Company, exhibit such disparity in the succession of strata that a clay or gravel bed in one can not with any certainty be recognized in the other. The easternmost wells of this group have much less clay than those farther west.

Outside the artesian area, well records show but little of the clay element. A number of records have been examined from the vicinity of Arrowhead station eastward, and, as is to be expected, the drill penetrates a succession of sand and of coarse and fine gravel strata with only here and there a thin bed of clay, or sandy clay or hardpan. The important element in artesian conditions, the superincumbent impervious cover, is absent from the records here, and it is quite unlikely that it would be found at any depth.

The wells drilled in the Lytle Creek wash likewise show a preponderance of coarse material, with only an occasional bed of clay or of cement, the latter acting in many cases as the impervious cap. In the group of wells about the old cienaga a few feet of peaty soil, representing the swamp growth on the original site of the springs, is penetrated by the drill near the surface. One record gives the depth of this organic matter as 24 feet.

The records discussed thus far have been exclusively from the later alluvium, which fills the present valley bottoms and is much more important as a source of water than the older folded beds of the earlier alluvium.

An examination of the records from the latter formation, abou Redlands, in Yucaipe and San Timoteo canyons and in Yucaipe Valle (figs. 7 and 8), discloses the fact that while not lacking in bowlder an gravel beds, although these are less abundant and less extensive tha in the later alluvium, the cobble beds, when they do occur, are ofte sealed. Their interspaces are not open, but are filled with clay, whic renders the beds practically impervious to water. Artesian water

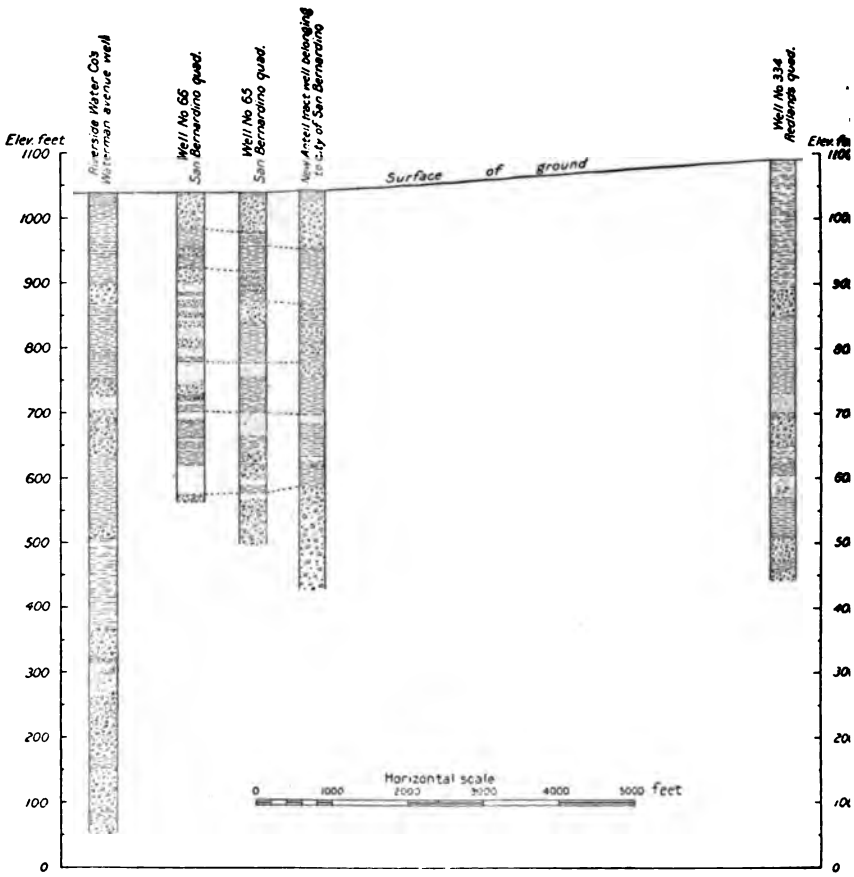


FIG. 6.—Well sections along line E-F, Pl. XII.

are found, however, in the older alluvium when open gravels ar encountered and the right structural conditions exist. Good example are the Dunlap group of wells in Yucaipe Valley, the flowing wells i the neighborhood of Singletons in San Timoteo Canyon, and the ho wells in the Badlands north of Moreno. Water is found under pres sure, so that it rises above the stratum in which it was encountered but it does not flow in the wells of the Redlands Water Company nea

ity reservoir and in a number of wells recently d in Yucaipe Canyon between its mouth and)unlap ranch (fig. 8).

e explanation of this difference between the rds of the wells in the older and the newer allu-, the preponderance of the clayey element in former, is probably to be found in a considera- of the conditions under which each originated. will be remembered that the first alluvium is eived to represent the detrital products which streams swept into the lowlands as a result of vigorous revival with the first uplift of the Bernardino Mountains to an elevation less than which they have now by 2,000 or 2,500 feet. re this uplift, although the surface exhibited nct relief, the predominant features were the valleys which separated the relatively low hills. ion before the uplift was not especially active, at opportunity for rock decay was much better now. The ultimate products of all rock decay lays, hence a clay mantle must have covered of that earlier surface. With the uplift which ed the streams and set them at work cutting ons and depositing the products of that activity adjacent wide valley as the earlier alluvium the er part of this clay mantle was swept away and ed an important part of the resulting deposits. ingled with the bowlders, which were the direct ucts of the canyon cutting, or settled in basins ively free from coarser material as nearly pure beds. When the second uplift came and the d epoch of sedimentation began, the earlier, abundant clays were practically all gone, and sands and gravels and those clays which are but flour ground up in the erosional processes ted. Some of the earlier clays lying long upon surface where they formed were well oxidized, re therefore red. Red clay bands in the earlier ium testify to this origin. The clays inter- ed with the modern gravels of the San Bernar- cienaga are never of this color.

nother very much less potent cause of the differ- in clay contents between the earlier and the alluvium, but one which may have exerted influence, is the great difference in the amount ater discharged upon the two formations. All

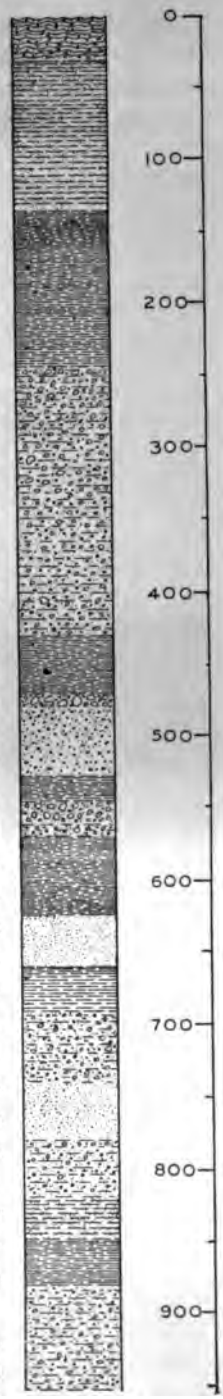


FIG. 7.—Section of the South Mountain Water Company's deep well in Yucaipe Valley.

of the important streams - Lytle Creek, Cajon Creek, East Twin Creek, City Creek, Plunge Creek, Mill Creek, and Santa Ana River—flow out upon the later alluvium and sink into it. The older alluvium gets only the local rainfall and the drainage from the southern slope of the San Bernardino Mountains between Mill Creek and San Gorgonio Pass. The amount of water seeking underground passage through the older beds is many times less than that which is concentrated in the later, so that whatever carrying and scouring power water percolating underground may have to clear bowlder beds of their fine interstitial material is much more efficiently exerted in the later than in the older beds.

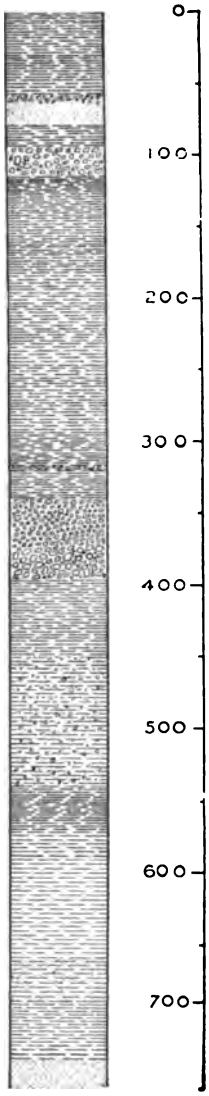
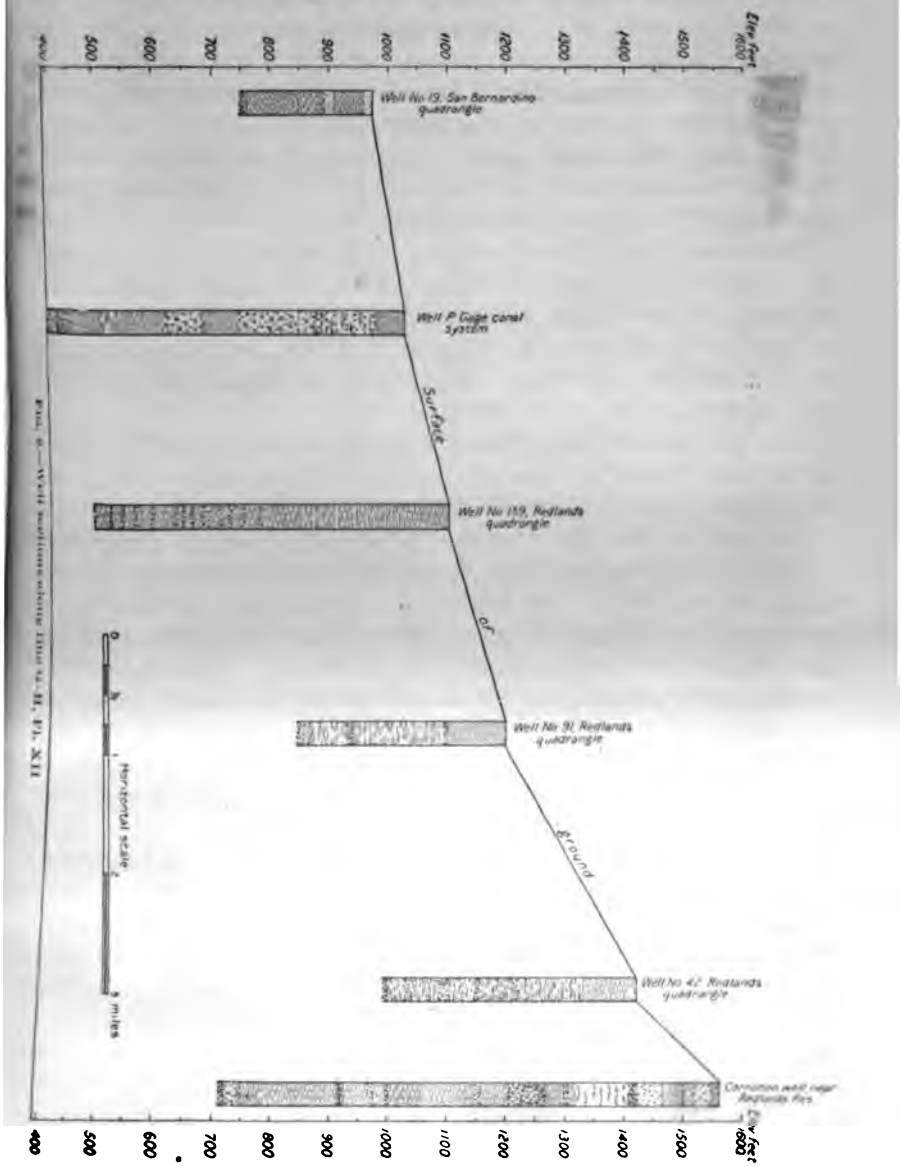


FIG. 8.—Section of Frink Brothers' well in Yucaipe Canyon.

It is to be remembered also that the earlier alluvium is the product of erosion brought into play by a less pronounced relief than that of the present, and therefore less vigorous and yielding finer material. This condition may have had its influence in bringing about the differences which exist between the two deposits.

The abrupt changes from conditions under which extensive coarse bowlder beds were deposited to those resulting in the deposition of fine clays, as shown in the well sections of the San Bernardino cienaga, admit of two or three explanations. Minor phenomena of this character are probably adequately accounted for on the hypothesis of shifting river channels. There are abundant historical examples of limited action of this kind, if historical proof were needed, but the existence of an alluvial fan is itself proof that the stream which built it has at different periods flowed down different radii of the fan. A stream on a growing fan is constantly building up its bed. As soon as that bed becomes enough higher than an adjacent tract to give the latter a steeper grade, the stream during some flood will break through the low confining banks which it has built and flow in the more advantageous channel until that has been built high enough to be abandoned in turn for a lower course. Thus the fans grow. The process is most obvious in the upper, steeper parts, where stream action is the paramount force. It is probably essentially the same in its lower course, but with less abrupt and violent action and more effective modification by other agencies, such as the growth of vegetation and the formation

of wind-blown sand dunes. Yet in most cases it is very effective here. The action of these arid-land streams during the periods of flood is like that of normal streams in that the greatest volume of water, the



swiftest current, and the greatest carrying power are concentrated in a main channel and a more moderate current and a greatly lessened carrying power are found outside of this channel on the adjacent

flooded lands. Coarse and heavy material is therefore transported and finally deposited in the channel, while only fine material is carried out over the adjacent flood plain. A train of coarse gravel may thus extend from the head of the fan far down the stream's course, while on either side of it the contemporaneous deposits are fine silts which eventually harden into impervious clays. When a river channel shifts in the growth of the fan in the manner sketched above, what was formerly the river bed may be abandoned entirely or be reached only by the thin edge of the flood waters, which deposit only sands or fine silts. These are in this manner laid down over previously deposited gravels, producing the sharp alternations which the well sections often reveal.

Where deep and laterally extensive bodies of gravel exist beneath the present surface, such as the one which underlies the Victoria tract of the Gage Canal Company and apparently extends west in the direction of Colton as far as the Bunker Hill dike, their presence at least suggests climatic conditions at the time of deposition which were different from those of the present.

Now, gravels are deposited only in the narrow washes which form the channels of the streams and only as incidents of the major floods. In the lower part of the Santa Ana wash, at present, the greater part of the surface alluvium is sand, bowlders and coarse gravels being relatively unimportant. But the gravel stratum under consideration, which is from 100 to 200 feet thick over an area of at least one and probably of several square miles, appears from the drill records to be even coarser and heavier than the surface wash. Seemingly the conditions which resulted in the deposition of the latter are scarcely adequate to account for these coarse cobbles. It may be that slight differences in climate existed when these gravels were laid down. An increase of a few inches in the annual rainfall at present would greatly stimulate stream activity and result in transporting coarse material to much greater distances from the canyon mouths than now. Especially would this be true if such a period of increase were to follow one of drought, during which the fans were steepened by the dropping of stream loads on the upper slopes because of the decreased transporting power due to the lessened rainfall. These periods of increased and lessened rainfall, if they really are to be regarded as one of the causes of the alternation of coarse and of fine deposits, must have been centuries long. Measured in inches, the accumulations by river deposition are very slight for any single year. One or two hundred feet even of coarse alluvium must have required at least as many years to accumulate as there are feet of material, and the finer deposits represent a much longer time, as they represent slower deposition. Yet, geologically, the time required for the filling of the entire San Bernardino basin has been but short. Well-preserved trunks of trees are cut by the drill at depths of several hundred feet. They are dark-

ne ground-water level and continue their course by percolation
ugh the porous accumulations. This was the habit of all streams
utary to San Bernardino Valley previous to their appropriation at
canyon mouths for irrigation purposes. Only a part of the rarer
ls following heavy winter rains reach the sea over the surface.
enever in their subterranean course the waters encountered an
ervious barrier of any kind, they accumulated behind it until they
to its level and flowed over it, precisely as stream waters are ponded
: of a dam until they rise to the level of its crest. When such an
ruction extended to the surface of the ground the waters were forced
ıs springs and again became surface flows. In southern California
e lands of rising waters are given the old Spanish name "cienaga."
enerally in the alluvial material where ground waters exist under
sure the compact stratum, whatever be its nature, which confines
ı is not entirely impervious. There is leakage through it, and
leaks, when they extend to the surface, become the springs
h characterize the cienaga lands. In almost every instance those
ı which, as the region developed, became important artesian
ıs were recognized as moist land before development through
occurrence of these springs, but, although the cienagas in so
r cases proved to indicate artesian conditions, and the greater
ian basins were always indicated by them, a few of the minor
ıs are not thus marked, and the distribution of the springs in
mportant basins sometimes fails to give any adequate guide to
extent or outlines of the artesian area. It is rare, of course,
a subsurface dam extends just near enough to the surface to
the percolating waters out without expressing itself topograph-
A ridge, or at least a series of mounds, is apt to be found

upon a smaller water supply, cause a relatively much larger evaporation and result in the deposition of a greater percentage of the contained alkalies. These, in some instances, act as a firm cementing material, particularly where calcium carbonate is an abundant salt, so that the site of the spring may be built up into a low alkaline terrace, which interrupts the even slopes of the desert wash. The Box S Springs, just north of the San Bernardino Mountains, are an example of this class of cienaga.

UNDERGROUND CIRCULATION.

A fact which has already been frequently mentioned is that the waters of the living mountain streams during periods of normal flow disappear promptly in the gravels at the mouths of the mountain canyons. The greater discharges of the minor floods are likewise usually absorbed before they have passed far out upon the stream washes. Only a part of the infrequent greater floods escapes to the sea as a surface flow. These absorbed normal and flood waters percolate slowly seaward underground along courses which are determined by the extent and permeability of the valley filling and by the presence or absence of impervious obstructions, such as buried or partly buried bed-rock masses, or of folds in the alluvium itself, which may deflect or obstruct the waters.

When experiments have been made to determine the rate and direction of movement in the ground waters, it has usually been found that the flow is in the direction in which the general water plane slopes, although local exceptions may exist. The general position and attitude of this plane in San Bernardino Valley have been determined at two periods (Pl. VII). Its slope, although not uniform, is general toward the lowest part of the valley occupied by the Santa Ana wash. It is in the same direction, although not at the same rate, as the surface gradient. The seepage of the underground waters, which is generally slow, although at a varying rate, is, like the surface slope, toward the lowest point of the basin. The rate of seepage, however, is much greater along the lines of the porous gravels which mark the washes of the present and of the past than in the interareas of sand and soil and clay. So great is the difference in rate that it seems likely that the form of the water surface undergoes a more or less regular annual alteration. It is believed to arch along the line of the washes during the rainy season, draining slowly from these laterally, toward the less pervious areas on either side. During the dry season, on the other hand, when the open material of the washes, draining freely because of its porosity, loses its waters before the adjacent soils, the surface of the water plane is depressed in the vicinity of the washes. The adjacent lands then drain toward the washes, as they drain away from them during the wet season. Such

a zone in which there is a seasonal reversal of the direction of percolation may be expected to border the loose gravels of all flood-water channels (fig. 10).

The checking of the rate at which the water moves seaward, as soon as it sinks into the rubble of the valley alluvium, together with the fact that the porous buried strata through which it percolates have no definite banks as have surface streams, results in the spreading out of the water beneath the surface into a broad zone through which it moves seaward at varying rates. In San Bernardino Valley these zones, representing the percolation from the mountain tributaries, Lytle Creek, Cajon Creek, Devil Canyon, East Twin Creek, Plunge Creek, and Santa Ana River and Mill Creek, and in winter from the direct rainfall within the valley itself, converge in the basin about San Bernardino into the wide, irregular area 40 or 50 square miles in extent and situated near the center of the valley, which is especially valuable because of the accessibility of its stored water.

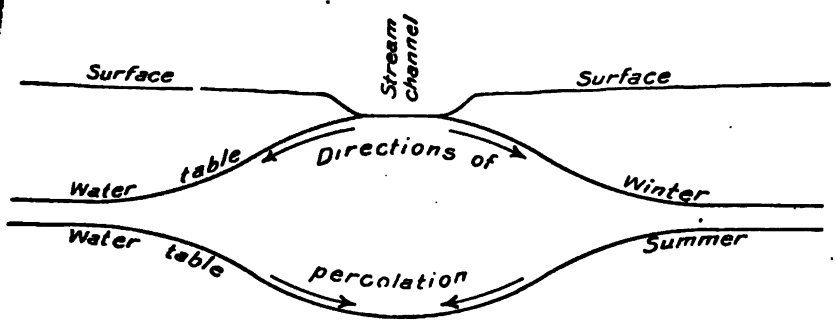


FIG. 10.—Diagrammatic cross section of summer and winter water table beneath a stream channel.

The interareas between these zones, where they are saturated, probably receive their waters, in part at least, by lateral seepage from the zones themselves. The rate of movement through the gravels in San Bernardino Valley has not been investigated. Measurements of the rate where comparable conditions exist have been made by Prof. C. S. Slichter[a] in Mohave River near Victorville, Cal., and in the Paso de Bartolo, through which the waters of the San Gabriel flow; and by Mr. Homer Hamlin[b] in Los Angeles River in and above Los Angeles, Cal. At Victorville velocities of 6, 8, 20, 35, 48, and 64 feet a day were determined, and an average of 50 feet has been assumed. In the Paso de Bartolo the much lower rates of 3½, 4, 5½, and 7 feet a day were determined. In the extensive series of tests made by Mr. Hamlin, extremes ranging between 0 and 96 feet a

[a] Slichter, Charles S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 43 et seq.

[b] Hamlin, Homer, Underflow tests in the drainage basin of Los Angeles River: Water-Sup. and Irr. Paper No. 112, U. S. Geol. Survey, 1905.

day were measured. Measurements were attempted on many strata which gave results lower than could be detected by the methods used. Mr. Hamlin believes that his methods are sufficiently refined to measure a movement of less than 1 foot a day, so that where no flow was detected it is assumed that the alluvium is practically impervious.

The average flow in 26 of Mr. Hamlin's tests, all of which gave measurable rates of movement, is 23 feet a day in round numbers. Since the majority of these tests were made in the narrows of Los Angeles River, 20 miles below the mouth of Tujunga Canyon, it may be assumed that at least as high an average velocity is maintained through the pervious strata in the Santa Ana River wash above Colton. It may be, indeed, that a higher average is maintained there. Twenty-three feet a day is 8,395 feet, or a little more than 1½ miles, a year. At this rate waters which enter the gravels at the head of the Santa Ana wash would appear at the Bunker Hill dike seven or eight years later. The facts probably are that a portion of these waters appears there in very much less time, while another portion, passing through less pervious strata, requires a much longer time. The effective percolation is always that of the greater rate through the coarser material, since its discharge of available water is vastly greater than that of the slower percolation.

The fact that the water plane all over the basin responds promptly to an increase of rainfall is not an argument against the deliberate movement of the underground water. The water plane rises as a hydrostatic effect of the introduction of more water at any point within the basin and not as a result of flow from the point of entry to all the points affected.

The rate at which flood waters are absorbed by the alluvial gravels and the total amount thus added to the underground reservoirs by any given storm are matters of great interest but are difficult to determine. Mr. W. B. Clapp, hydrographer, conducted a series of measurements of a number of streams in southern California during the spring of 1903 to determine the rate of absorption of flood waters. On April 16 of that year a moderate rain accompanying a low temperature resulted in a small flood discharge and a well-maintained later flow, as much of the precipitation was in the form of snow at the greater altitudes. On April 24 the streams discharging into the San Bernardino basin were measured and the proportions of this flow diverted and absorbed were determined. The measurements were made with a limited force, and therefore it was not possible to carry them out at as many points as was desired. Nevertheless the results are of great interest. Similar measurements were made on May 16 and the results of both are shown in the accompanying table, which gives the total amount of water absorbed by the alluvium during the two twenty-four-hour periods.

Amount of water discharged in twenty-four hours from tributary streams and sinking in Santa Ana River basin above Colton, Cal.

[W. B. Clapp, hydrographer.]

APRIL 24, 1903.

Stream.	Diversions.	Waste.	Diversions.	Waste.	Total.	
	Cubic feet.	*Cubic feet.*	*Acre-feet.*	*Acre-feet.*	*Cubic feet.*	*Acre-feet.*
Santa Ana	1,382,400	10,022,400	32	230	11,404,800	262
Mill Creek	432,000	6,998,400	10	161	7,430,400	171
Plunge Creek	.....	1,987,200	.....	46	1,987,200	46
City Creek	.....	1,900,800	.....	44	1,900,800	44
East Twin Creek	.....	864,000	.....	20	864,000	20
West Twin Creek	.....	743,040	.....	17	743,040	17
Lytle Creek	561,600	4,881,600	13	112	5,443,200	125
Total	2,376,000	27,397,440	55	630	29,773,440	685

MAY 16, 1903.

Santa Ana	4,060,800	4,147,200	93	95	8,208,000	188
Mill Creek	4,233,600	1,641,600	97	38	5,875,200	135
Plunge Creek	518,400	259,200	12	6	777,600	18
City Creek	604,800	345,600	14	8	950,400	22
East Twin Creek	172,800	259,200	4	6	432,000	10
West Twin Creek	172,800	172,800	4	4	345,600	8
Lytle Creek	1,296,000	1,209,600	30	28	2,505,600	58
Total	11,059,200	8,035,200	254	185	19,094,400	439

The rate at which this absorption took place is indicated for one of the streams, the Santa Ana, by fig. 11. During the earlier measurement, that of April 24, a flood of 197 second-feet was completely absorbed in 8 miles, while on May 16 a flow of 67 second-feet had disappeared within a distance of 5 miles, more than one-third of the loss occurring in the last half mile, when the velocity was least.

During the first measurement water from the measured streams was flowing into the underground reservoir at the rate of about 317 cubic feet a second, and during the last measurement at the rate of about 100 cubic feet a second. It is of interest to note that the first rate is somewhat more than double that at which water is withdrawn from the same basin during the irrigating season, while the later measurement indicates absorption at a rate equal to two-thirds of the rate of withdrawal during the irrigating season. During great floods this recharge must take place at a very much greater rate, but it is evident that this

is necessary, since it continues for a comparatively brief period, while the withdrawals are continuous for nine or ten months of the year.

ORIGIN OF HEAD WITHIN THE ARTESIAN BELT.

The alluvial deposits of the streams tributary to the San Bernardino basin have been laid down by the streams as they have built the sloping plain upon which they now flow. All of the deposits, fine and coarse, therefore have a distinct dip toward the lowest part of the basin. All of these strata abut against the arch in the earlier alluvium, which is known as the Bunker Hill dike. Where coarse beds in the lower part are capped by finer ones, which either are

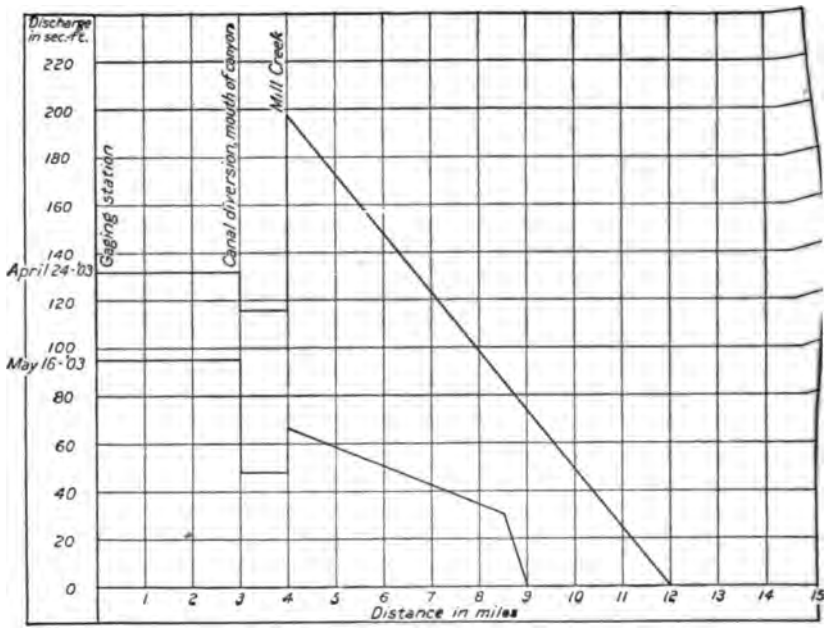


FIG. 11.—Diagram showing sinking of flood waters of Santa Ana River in stream bed.

impervious or are so compact that water leaks upward through them more slowly than it enters the coarse underlying strata, artesian conditions result. As the gravel and bowlder beds and the finer overlying clays and sands occur at a number of horizons, water under pressure is found at a number of depths within the artesian area. The wells whose yield has been greatest are of moderate depth. Three of the Gage wells, all less than 200 feet deep, flowed more than 400 inches of water each in 1892. Four others are reported to have yielded nearly 300 inches each in the same time. Two of these wells were 300 feet deep or less, one was 426 feet, and another 582 feet deep. All have ceased flowing or have greatly decreased in yield, but the shallower ones were the earliest exhausted. One of the best yielding wells of the

Riverside Water Company originally was a 330-foot well in the tract which furnishes the city of Riverside with its domestic supply. Two other famous wells belonging to the water company, about 2 miles east of San Bernardino, flowed between 150 and 200 inches of water each when they were first put down. They were drilled in 1900, and have been among the most productive of the late wells. The yield from them has fallen off greatly of late, but they have not ceased to flow. One of the new wells put in by the city of San Bernardino in the Antill tract in 1904 measured at the time of its completion somewhat more than 90 inches. A 984-foot well belonging to the Riverside Water Company, situated near the intersection of Waterman avenue and Third street, and yielding about 120 inches, is now one of the strongest flowing wells in the valley, although earlier wells have at some time flowed several times as much. The experiences of the water companies go to show that while the coarsest gravels and the freest flows have been secured at very moderate depths, the head under which these waters exist is easily drawn down. The deeper wells are more lasting, although usually more moderate in their first yield.

A not unusual experience in San Bernardino Valley is to secure a first flow from a shallow well 100 or 200 feet deep, and after this has ceased to flow with the lapse of years, to sink a deep well in the same vicinity and again secure a satisfactory flow from a lower horizon. The direct inference from these phenomena is that the water-bearing beds are separated by intervening strata of clay or fine sand, and so are independent sources of water under different heads. Another hypothesis advanced by the engineers of the district is that all the waters of the basin are under the same head, originating in the lowest artesian stratum, but that much pressure is lost through frictional resistance, as these waters rise from the lowest level through fine-grained beds to the coarse beds above; when they are tapped at a higher level, therefore, they are under much less pressure than when tapped at deeper points. This hypothesis requires that all pressures originate in a lower bed, and means that all of the artesian waters within the San Bernardino cienaga rise from this lowest horizon.

The other hypothesis, that of separate water horizons with independent intakes—those of the shallower beds well down from the canyon mouths toward the center of the basin, those of the deeper beds farther up toward the head of the alluvial fan—supposes all the waters to be simply percolating waters at any horizon, which have been caught beneath the upstream edges of the various impervious clay masses as they have worked seaward. Since these clays exist at various horizons, their confined waters are tapped at various depths.

To determine which of these hypotheses is correct would require a series of carefully conducted experiments upon the interdependence

of deep and shallow wells. The experiments first conducted by l fessor Hilgard[a] upon the interdependence of the wells of the G canal system in 1889 throw no light upon the relations exis between wells of greater and of less depth, since the only wells avail for measurements and in any way involved at that time were the e shallow bores less than 200 feet deep.

The later extensive series of records made by the engineers of Gage system in the fall of 1892 upon the 55 wells which were source of supply for the canal at that time, while not carried out v the idea of distinguishing between deep and shallow wells, or of sh ing the interdependence of these grouped according to their depth. throw some light upon the problem. The essential results of th measurements are assembled in the following table:

Records of wells of Gage canal system, San Bernardino, Cal.

Quadrangle.	No. of well	Serial No.	Distance of nearest well.	Depth of well.	Elevation.	Size of well.	Temperature of water.	Original measurements.	Final measurements.	Per cent decrease from original to final measurements.	Cumulative total of original measurements.	Cumulative total of final measurements.
			Yards.	*Feet.*	*Feet.*	*In.*	*° F.*	*Miner's inches.*	*Miner's inches.*			
San Bernardino.	115	1	0	656	1,033.15	10	75	5.00	5.00	0	5.00	5.00
Do....	116	2	1,216	534	1,033.63	10	71	46.00	32.50	30	51.00	37.50
Do....	117	3	296	582	1,033.75	10	74	37.00	29.00	22	88.00	66.50
Do....	118	4	525	482	1,033.96	10	71	48.75	41.25	15	136.75	107.75
Do....	119	5	561	320	1,034.19	10½	73	3.50	3.50	00	140.25	111.25
Do....	120	6	265	784	1,034.29	10	74	51.75	45.00	13	192.00	156.25
Do....	121	7	4,620	196	1,036.11	10½	70	27.50	13.75	50	219.50	170.00
Do....	122	8	333	190	1,036.28	10½	70	46.00	21.00	55	265.50	191.00
Do....	123	9	204	142	1,036.36	10	70	9.75	3.50	64	275.25	194.50
Do....	124	10	321	148	1,036.49	10½	68.5	6.00	3.25	46	281.25	197.75
Do....	125	11	714	141	1,036.78	7	67	58.00	24.50	58	339.25	222.25
Do....	126	12	80	181	1,036.81	7	68	49.75	21.62	57	389.00	243.37
Do....	127	13	765	426	1,037.12	10	70	150.00	86.50	43	539.00	330.37
Do....	128	14	530	472	1,037.33	10	70	162.00	101.50	37	701.00	431.87
Do....	129	15	1,680	518	1,048.22	10	64.5	80.50	62.50	23	781.50	494.37
Do....	130	16	180	388	1,048.66	10	66	60.50	50.00	18	842.00	544.37
Do....	131	17	175	380	1,049.23	10	65	37.50	32.00	15	879.50	576.27
Do....	132	18	480	386	1,049.44	10	62	71.50	27.00	63	951.00	603.37
Do....	133	19	330	198	1,052.44	10	62	143.00	43.50	70	1,094.00	646.87
Do....	134	20	270	124	1,056.94	10	62	60.00	9.50	84	1,154.00	656.37
Do....	135	21	260	116	1,055.16	10	62	104.00	24.75	77	1,258.00	681.12
Do....	136	22	270	134	1,056.75	10	62	146.00	50.50	66	1,404.00	731.62
Redlands.	391	23	265	168	1,057.81	10	62	132.50	36.00	73	1,536.00	767.62
Do....	392	24	265	166	1,058.67	10	62	68.75	26.00	62	1,605.25	793.62
Do....	393	25	320	152	1,060.88	10	62	68.75	19.75	71	1,674.00	813.37
Do....	394	26	280	123	1,063.34	10	62	75.00	21.00	72	1,749.00	834.37
Do....	395	27	320	125	1,065.60	10	62	34.00	9.00	73	1,783.00	843.37

[a] Hilgard, E. W., Subterranean water supply of the San Bernardino Valley: Bull. No. 119, Off Exp. Sta., U. S. Dept. Agric., p. 116.

Records of wells of Gage canal system, San Bernardino, Cal.—Continued.

Land-mark.	No. of well.	Serial No.	Distance of nearest well.	Depth of well.	Elevation.	Size of well.	Temperature of water.	Original measurements.	Final measurements.	Per cent decrease from original to final measurements.	Cumulative total of original measurements.	Cumulative total of final measurements.	Percentage of loss in final total.
			Yards.	*Feet.*	*Feet.*	*In.*	° *F.*	*Miner's inches.*	*Miner's inches.*				
sinds.	396	28	280	144	1,062.28	10	62	88.50	38.00	58	1,871.50	881.37	53
Do....	397	29	310	140	1,064.27	10½	62	47.00	28.85	39	1,918.50	910.22	53
Do....	398	30	790	138	1,075.05	10	62	30.00	11.25	63	1,948.50	921.47	53
Do....	399	31	430	106	1,074.58	10	64	9.50	3.75	60	1,958.00	925.22	53
Do....	400	32	35	130	1,074.28	10	64	28.50	16.25	48	1,986.50	941.47	53
Do....	401	33	315	146	1,070.72	10	63	90.00	41.00	55	2,076.50	982.47	53
Do....	402	34	550	116	1,064.69	10	63	98.30	48.00	52	2,174.80	1,030.47	53
Do....	403	35	130	134	1,063.49	10	63	65.75	30.50	54	2,240.55	1,060.97	53
Do....	404	36	120	116	1,060.89	10	64	29.50	16.00	46	2,270.05	1,076.97	53
Do....	405	37	680	147	1,057.05	10	66	92.00	42.00	55	2,362.05	1,118.97	54
Do....	406	38	90	122	1,058.15	10	66	48.75	28.75	41	2,410.80	1,147.72	53
Do....	407	39	279	115	1,059.01	10	66	24.75	10.50	58	2,435.55	1,158.22	53
Do....	408	40	1,090	160	1,053.14	10½	66	166.00	77.15	53	2,601.55	1,235.37	53
Ber-sdino.	155	41	474	193	1,050.54	10	66	168.00	69.50	58	2,769.55	1,304.87	53
Do....	156	42	510	192	1,046.29	10	66	169.00	85.75	50	2,938.55	1,390.62	53
Do....	157	43	510	390	1,044.13	10½	66	137.00	109.75	20	3,075.55	1,500.37	52
Do....	158	44	307	224	1,041.76	10	64	146.00	92.75	37	3,221.55	1,593.12	51
Do....	159	45	1,580	123	1,044.87	7	62	46.25	16.50	60	3,267.80	1,609.62	51
Do....	160	46	15	133	1,044.87	7	62	16.75	6.70	60	3,284.55	1,616.32	51
Do....	161	47	15	133	1,045.02	7	62	66.00	26.40	60	3,350.55	1,640.72	52
Do....	162	48	40	139	1,047.67	5	62	50.84	29.33	60	3,401.34	1,670.05	51
Do....	163	49	50	211	1,047.87	7	62	76.00	26.40	60	3,477.39	1,698.45	52
Do....	164	50	40	100	1,046.42	7	62	20.00	15.00	25	3,497.39	1,713.45	51
ands.	409	51	4,440	127	1,077.27	7	64	7.00	.00	100	3,504.39	1,713.45	52
Do....	410	52	20	127	1,076.83	7	64	7.10	.00	100	3,511.49	1,713.45	52
Do....	411	53	25	125	1,077.14	7	64	7.00	.00	100	3,518.49	1,713.45	52
Do....	412	54	25	125	1,077.45	7	65	10.50	.00	100	3,528.99	1,713.45	52
Ber-lino.	169	55	5,070	300	1,036.71	10	64	150.00	80.00	56	3,678.99	1,793.45	52

he total flow when all the wells were open was 52 per cent less than cumulative total yielded by adding the results obtained by meas- g each well when all others were closed. If the wells are grouped rding to depth, however, some significant relations are brought out. f the 55 wells, 39 are less than 200 feet deep. The decrease in the vidual flow of these wells from a maximum, when all but one are ed, to a minimum, when all are open, ranges from 25 to 100 per , and the total when all are open is 62 per cent less than the cumu- e total. Eleven of the 55 wells are between 200 and 500 feet . The decrease in the flow of individual wells in this group, lting from the opening of all the wells, varied between 0 and 63 cent, and the falling off from the cumulative total to the final

total was 33 per cent, about half that of the much larger group of shallower wells. A third group of 5 wells, ranging in depth from 500 to nearly 800 feet, showed individual decreases in flow, as the other wells were opened, from 0 to 37 per cent, with an average of 18 per cent—much less than either of the shallower groups. When the wells are grouped in this way and the data examined, it is clear that, on the whole, the deep and the shallow wells behaved very differently during the tests.

The shallowest wells, forming the largest group, show the greatest individual and average decrease; a second group, intermediate in number of wells and in depth, shows an intermediate decrease; while the smallest group, consisting of the deepest wells, shows the least falling off in yield as the other wells are opened.

It seems safe to conclude from this showing that there is not free connection between the shallower and the deeper water-bearing horizons; indeed, the wells of each group behave much as would be expected if they tapped wholly independent sources of water. It is not probable, however, that this is true. The irregular character of the alluvial deposits, the abundant unconformities and local channels within them, and the fact that each bed of clay and gravel is probably quite limited in lateral extent, make it probable that imperfect and devious connections exist between the deeper and the higher water-bearing horizons. The alluvial fans do not give the ideal artesian conditions of a practically impervious cover and a pervious underlying stratum, but rather of a less pervious superincumbent bed and a more pervious water-carrying bed below. Just as the water leaks through the topmost clay cap of the Warm Creek and Santa Ana basins to the surface as springs, so it probably leaks from the lower horizons into the upper. So long as this leakage is less rapid than the supply of water to the bed through natural sources, pressure will be maintained and artesian conditions will continue. Imperfect connection of this sort probably exists between the chief water-bearing horizons throughout the artesian basin, and it may account for the reported sensitiveness of deep or shallow flowing wells to pumping in shallow or deep ones near by.

DECLINE OF THE WATERS.

Water users throughout the valley have felt in various ways the general diminution of the supply of underground waters within the last ten years. The large irrigating and domestic companies have been affected through the lessened flow of surface streams upon which they formerly depended for a large part of their supply or through the diminished yield of wells and the necessity of installing pumping plants where originally naturally flowing waters sufficed.

Local users, ranchers, and others have found that lands formerly

moist enough for pasture and ordinary crops are now dry and require irrigation, and that domestic wells must be frequently deepened in order to follow the declining ground water. In some cases the question of supply is becoming acute and the increased cost of water almost prohibitive for certain crops in unfavorable localities. Personal bitterness often results and suits are instituted to prevent developments on adjacent land.

About the general fact of the decline of the ground waters and of the lessened flow of wells there is no dispute (fig. 12 and Pl. VII). The relation of this decline to decreased rainfall on the one hand and to the drafts upon the stored underground waters through developments of various kinds upon the other is a subject of earnest discussion, and, indeed, upon a correct answer to it must depend the future attitude of the citizens toward further reclamation of lands and toward the successful maintenance of a part of those already reclaimed.

Changes in water level in wells in Redlands quadrangle between 1900 and 1904.

No. of well.	Owner.	Location.	Elevation of surface.	Elevation of water. 1900.	Elevation of water. 1904.	Change in water level.
			Feet.	*Feet.*	*Feet.*	*Feet.*
1	Doctor Meeker	Sec. 16, T. 1 S., R. 2 W.	1,996	1,718	Dry.	− 3+
2	Ward, Mills & Co	Sec. 21, T. 1 S., R. 2 W.	2,005	1,933	1,955	+22
5	Mrs. M. A. Brown	Sec. 22, T. 1 S., R. 2 W.	2,250	2,225	2,223	− 2
7	R. P. McIntosh	Sec. 20, T. 1 S., R. 2 W.	1,910	1,818	1,832	+14
9	L. Lyons	Sec. 16, T. 1 S., R. 2 W.	2,075	2,052	2,062	+10
14	W. J. French	Sec. 19, T. 1 S., R. 2 W.	1,720	1,560	1,556	− 4
28	Garland estate	Sec. 25, T. 1 S., R. 3 W.	1,570	1,394	(a)	−29+
42	C. L. Hayes	Sec. 27, T. 1 S., R. 3 W.	1,420	1,270	(b)	30+
43	O. W. Harris	Sec. 34, T. 1 S., R. 3 W.	1,503	1,303	(c)	3+
45	A. C. Fowler	Sec. 32, T. 1 S., R. 3 W.	1,250	1,140	Dry.	−60+
46	L. C. Smith	do	1,215	1,135	(d)	10+
48	E. Vache	do	1,260	1,200	1,182	−18
56	H. Bermudas	do	1,210	1,156	1,187	+31
60	R. T. Curtis	Sec. 29, T. 1 S., R. 3 W.	1,123	1,073	1,055	−18
66	Gansnor & Renwick	Sec. 30, T. 1 S., R. 3 W.	1,140	1,110	1,085	−25
80	Mrs. S. W. Sylvera	Sec. 29, T. 1 S., R. 3 W.	1,200	1,170	1,137	−33
83	S. Mansfield	do	1,193	1,154	1,143	−11
84	A. Lenanon	do	1,186	1,156	1,131	−25
94	W. A. Nichols	Sec. 28, T. 1 S., R. 3 W.	1,246	1,194	1,176	−18
102	Willis Miller	Sec. 21, T. 1 S., R. 3 W.	1,290	1,203	1,187	−16
109	C. A. Shaw	do	1,267	1,217	1,185	−32
113	A. Gregory	do	1,245	1,194	1,175	−19
117	S. Ronzone	Sec. 16, T. 1 S., R. 3 W.	1,257	1,192	1,166	26
120	M. R. Gay	Sec. 17, T. 1 S., R. 3 W.	1,220	1,170	1,145	−25
123	J. F. Boyd	Sec. 16, T. 1 S., R. 3 W.	1,290	1,180	1,180	0
124	Wm. Lindenberg	Sec. 20, T. 1 S., R. 3 W.	1,220	1,180	1,155	−23
125	H. S. Drew	Sec. 19, T. 1 S., R. 3 W.	1,167	1,133	1,137	+ 4
126	James Smith	do	1,164	1,130	1,113	17
130	Clark & Brotherton	Sec. 20, T. 1 S., R. 3 W.	1,195	1,162	1,147	−15
131	J. J. Pendergast	Sec. 29, T. 1 S., R. 3 W.	1,200	1,166	1,159	7
132	H. H. Cole	Sec. 30, T. 1 S., R. 3 W.	1,140	1,108	1,095	−13

a Dry at 1,365 feet. b 1902, 1,240 feet. c 1902, 1,300 feet. d Dry at 1,125 feet.

Changes in water level in wells in Redlands quadrangle between 1900 and 1904—Continued.

No. of well.	Owner.	Location.	Elevation of surface.	Elevation of water. 1900.	Elevation of water. 1904.	Change in water level.
			Feet.	*Feet.*	*Feet.*	*Feet.*
129	H. R. Scott	Sec. 19, T. 1 S., R. 3 W.	1,120	1,108	(a)	- 8+
145	E. F. Van Leuven	Sec. 25, T. 1 S., R. 4 W.	1,103	1,083	1,070	-13
155	F. Morris	Sec. 32, T. 1 S., R. 3 W.	1,260	1,195	1,165	-30
289	N. Sutherland	Sec. 4, T. 1 S., R. 3 W.	1,227	1,160	1,134	-26
290	Pattee & Nye	Sec. 5, T. 1 S., R. 3 W.	1,200	1,150	1,126	-24
291	G. J. Fowler	do	1,180	1,127	1,110	-17
292	R. F. Cunningham	do	1,160	1,120	1,105	-15
334	Mrs. Haws	Sec. 6, T. 1 S., R. 3 W.	1,125	1,125	1,115	-10
350	Jane C. Goodman	do	1,140	1,128	1,108	-20
386	State of California Hospital	Sec. 5, T. 1 S., R. 3 W.	1,110	1,078	1,064	-14

a Dry at 20 feet.

Changes in water level in wells in San Bernardino quadrangle between 1900 and 1904.

No. of well.	Owner.	Location.	Elevation of surface.	Elevation of water. 1900.	Elevation of water. 1904.	Change in water level.
			Feet.	*Feet.*	*Feet.*	*Feet.*
73	W. L. Zader	Sec. 29, T. 1 S., R. 4 W.	980	930	920	-10
76	Mrs. B. R. Atkins	Sec. 30, T. 1 S., R. 4 W.	980	938	923	-15
78	W. G. Soares	do	875	871	863	- 8
104	Riverside Trust Co.	Sec. 24, T. 1 S., R. 4 W.	1,077	1,077	1,072	- 5
178	G. W. Curtis	do	1,088	1,063	1,045	-18
181	W. A. Thomas	do	1,078	1,076	1,068	- 8
189	E. M. Cooley	Sec. 27, T. 1 S., R. 4 W.	1,019	959	977	+18
199	Washington School	do	1,043	966	961	- 5
201	Fred Pooles	Sec. 33, T. 1 S., R. 4 W.	955	907	895	-12
277	G. Renwick	Sec. 8, T. 1 S., R. 4 W.	1,090	1,055	1,050	- 5
280	E. Memory	Sec. 20, T. 1 S., R. 4 W.	982	927	920	- 7
282	C. H. Westmyer	Sec. 8, T. 1 S., R. 4 W.	1,069	1,062	1,048	- 14
316	Geo. M. Cooley	Sec. 36, T 1 N., R. 4 W.	1,150	1,108	1,090	-18
317	do	do	1,150	1,108	1,090	-18
317a	do	do	1,150	1,108	1,090	-18
318	E. J. Stiles	Sec. 35, T. 1 N., R. 4 W.	1,196	1,157	1,146	-11
319	Jas. Dickson	do	1,179	1,145	1,131	-14
329	Muscupiabe Land and Water Co.	Sec. 23, T. 1 N., R. 4 W.	1,288	1,143	1,115	-28
341	H. N. Stones	Sec. 34, T. 1 N., R. 4 W.	1,141	1,087	1,078	- 9
354	S. F. Kelley	Sec. 28, T. 1 N., R. 4 W.	1,170	1,121	1,095	-26
357	S. H. Johnson	do	1,182	1,122	1,082	-40
364	F. Alvarado	Sec. 32, T. 1 N., R. 4 W.	1,188	1,135	1,118	-17
367	D. W. White	Sec. 4, T. 1 S., R. 4 W.	1,109	1,089	1,074	-15
370	F. L. Holcomb	Sec. 33, T. 1 N., R. 4 W.	1,128	1,100	1,078	-22
375	Dexter Field	Sec. 5, T. 1 S., R. 4 W.	1,147	1,112	1,089	-23
389	S. E. A. Palmer	Sec. 33, T. 1 N., R. 4 W.	1,176	1,124	1,099	-25
398	N. M. Swarthout	do	1,142	1,115	1,094	-21
400	J. H. Lytle	do	1,166	1,135	1,086	49
416	H. H. Ham	Sec. 34, T 1 N., R. 4 W.	1,121	1,090	1,075	-15
445	A. W. Bemis	Sec. 5, T. 1 S., R. 4 W.	1,114	1,104	1,077	-27
450	M. D. Reynolds	do	1,116	1,094	1,076	-18
457	J. F. Cadd	Sec. 4, T. 1 S., R. 4 W.	1,068	1,057	1,052	- 5
458	H. E. Gardner	Sec. 5, T. 1 S., R. 4 W.	1,089	1,079	1,063	-16
470	Charles Morris	Sec. 26, T. 1 S., R. 4 W.	1,078	1,063	1,054	- 9

At one point within the valley systematic measurements of the water level have been continued through a term of years. For these measurements we are indebted to the Gage Canal Company, its enlightened management, and its able engineers. The "Williams" well, in which these measurements have been made, is near the east end of the Victoria tract, and on the south side of Santa Ana River. In 1892 and in the spring of 1893 this was a flowing well. It has not flowed since, but each year it has declined, until in June, 1904 the water level was 38 feet below the surface (fig. 12).

During the three years preceding 1898 the measurements were made only at long intervals and the details of the decline were not determined. Since that date measurements have been made frequently, and it is found that while the average condition is one of decline, this is at a varying rate, and is interrupted by periods of rise, so that a profile of the attitude of the water plane, with months used as the time units and feet as the units of elevation, exhibits a series of pulsations, the water level rising each spring in consequence of the winter rainfall and declining from that time until after the beginning of the next rainy season. These upward movements were especially marked during the springs of 1901 and 1903, the rainfall at San Bernardino in the preceding winters having been heavier than the average for thirty-four years. Between the 1st of October, 1900, and the 1st of April, 1901, the water level rose nearly 9 feet, and a rise of 8 feet is shown between February 1 and June 1, 1903, but the crest of the 1903 rise was 10 feet lower than that of the spring two years before, showing clearly the marked general lowering.

Again, a curve showing the average decline since observations began is markedly steeper during the period from 1896 to 1900 than before or since, thus indicating that, however many causes have been operative in producing the effect observed, the diminished rainfall during those dry years was a most potent factor. The situation of this well near Santa Ana River results in prompt responsiveness to periods of heavy precipitation or of drought, and accounts for the strongly marked annual fluctuations in water level, which are not observed in wells at greater distances from important waterways. In the latter cases the percolation of the flood waters for long distances through sand and gravel smooths out the waves and reduces them to an average.

Mr. Gudeman Johnson, north of San Bernardino, has kept a record of the water level in his well for some years past, and while there are some long intervals in it during which no measurements were made, it is sufficiently full to show the absence of such marked annual pulsations as are characteristic of the Williams record. Yet its general results are identical: It shows a decline of 27 feet from June, 1899, to June, 1904, a lowering of the plane of saturation of more than

5 feet a year. It likewise shows a markedly steeper gradient for the dry period preceding 1901 than for the four seasons following, during two of which, 1900–1901 and 1902–3, the precipitation at San Bernardino has been above the average of the last thirty-four years, although, since the deficiency during 1901–2 and 1903–4 was greater than the excess for the other two winters of the four, the final result is a deficiency for the period of more than 5 inches (fig. 13).

Although outside San Bernardino Valley and influenced somewhat by local conditions, a profile of the water plane at Anaheim, Cal., as determined by Mr. J. B. Neff, is here introduced for comparison (fig. 14), and for general confirmation of the effect observed in the case of the interior wells. The total decline of the water level in

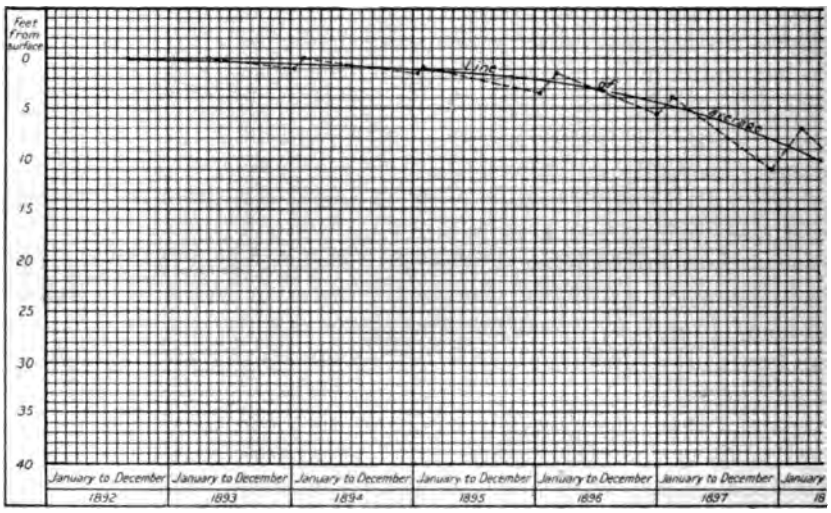


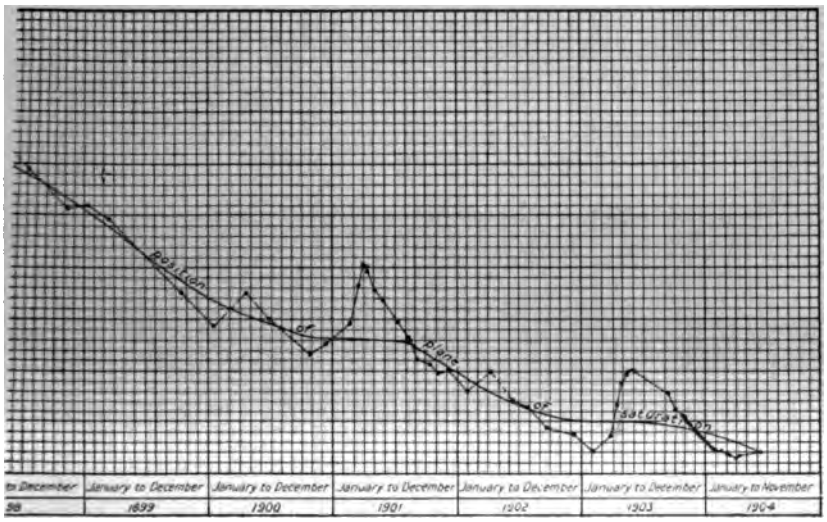
FIG. 12.—Chart showing variation

this well from the beginning of observations in February, 1898, to January 1, 1905, is 27 feet 8 inches. In this well also the lowering of the water level was much more rapid during the years preceding the winter of 1900–1901 than since. In it also there is a definite rise of the water plane during the early months of 1901 and 1903, although this rise is of smaller magnitude than in the case of the Williams well.

The significant thing about all of these profiles is that the gain effected during the winters of slight excess was in each instance lost before the end of the succeeding dry season. Only two doubtful points can be selected in the Williams profile in which the ground-water level is higher than at a corresponding time during the previous year. These two points are the crests of the floods of 1901 and 1903, and in every case the lowest point of any particular year is lower than the lowest point of the preceding year. This is true of the years

1900–1901 and 1902–3, during which the rainfall was 2 inches above the average. The loss in these cases was small, but distinct.

In Mr. Neff's well, at Anaheim, where the pulsations are distinctly less in magnitude, the loss between June 1, 1903, and June 1, 1904, was 2 inches, and between November 4, 1900, and November 8, 1901, 3 inches. These dates are the most favorable that can be selected, and each pair spans a year during which the rainfall exceeded the average by about 2 inches, or over 13 per cent. Years of more than average precipitation, then, have very decidedly checked the rate of decline of the ground waters, but have not brought about a cessation of that decline. The average precipitation will be even less efficient, and if maintained through a term of years during which



of water level in the Williams well.

there should be no change in the amount drawn from the basin, the surface of the stored subterranean waters would inevitably continue to fall, although, of course, at a less alarming rate than during the period preceding the winter of 1900–1901.

It is not possible with the data at hand to predict the effect of a series of wet years like the decade from 1883 to 1893, but such a prolonged wet period is not likely to occur again within a generation. A scrutiny of the available records shows that it has not been duplicated in a half century.

A very large percentage of a moderate precipitation evaporates at once or is required to moisten the surface soil. The proportion which as run-off becomes available for recharging the subterranean reservoirs increases at a rapidly accelerating rate as rainfall increases. At the same time less irrigation is necessary during winters of heavy

rainfall, and a large proportion of the reduced irrigation is accomplished by surface waters, the streams during such seasons flowing near their maximum. Hence, at such a time, drafts upon the underground supplies are diminished and additions to them are increased, resulting in a rapid improvement of conditions. Our profiles of water levels, however, indicate that such improvements will not be permanently effective in the San Bernardino basin unless the rainfall is in excess of 17½ inches, and records indicate that only one year in three exhibits such an excess.

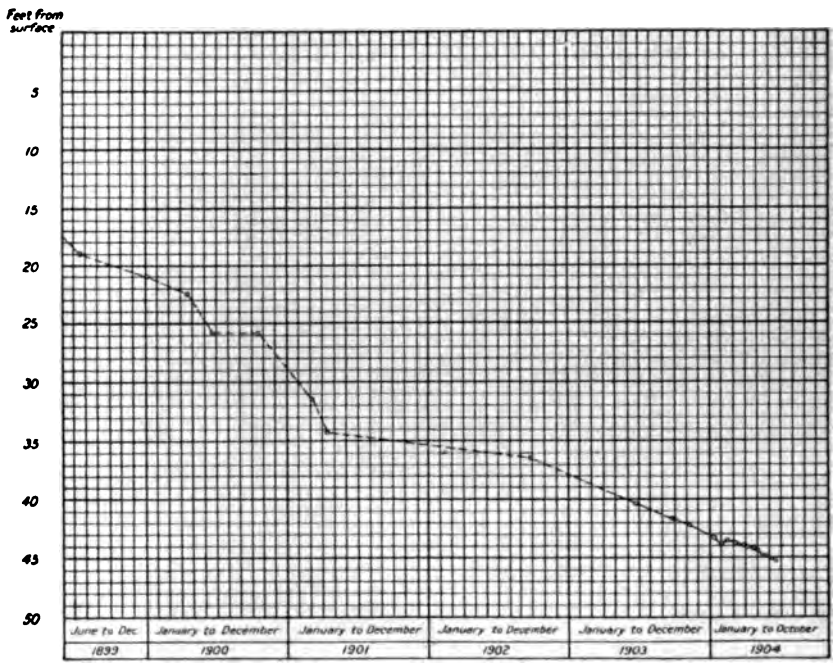
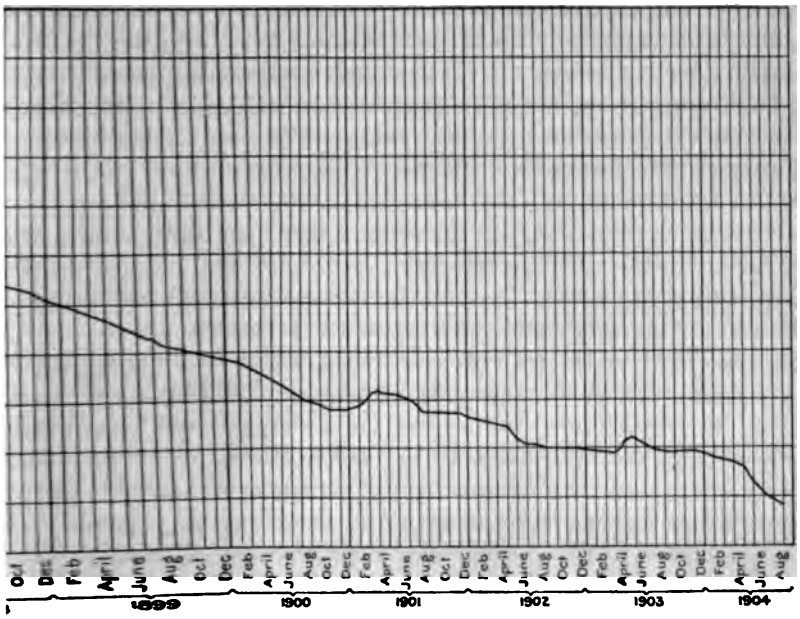


FIG. 13.—Chart showing variation of water level in the Johnson well, near San Bernardino.

Accompanying this decline of the ground waters there has been a definite decrease in the extent of the artesian basin. The San Bernardino basin was probably about at its maximum late in the eighties. At that time its area was approximately 30 square miles. In 1900, after the three especially dry winters of 1898, 1899, and 1900, it had shrunk to approximately 15.3 square miles, and at the beginning of 1904 there had been a further slight shrinkage to 14 square miles (Pl. VII).

A phenomenon which expresses the same condition as the falling water plane and the decreasing artesian area is that of decreasing pressure within the artesian belt. This results in a falling off in artesian flow and a lessening of the yield from springs which rise in the moist lands. The following table, in which the amounts of natural

ters and of developed waters within the basin during the last are shown, indicates the character of this change.



. 11.—Chart showing variation of water level in the Neff well, near Anaheim,

arison by years of flowing water and developed water above Colton, Cal.

[Kingsbury Sanborn, observer.]

Date.	Flowing water.	Developed water.	Total.
	Second-feet.	*Second-feet.*	*Second-feet.*
, 1898	78.31	66.38	144.69
899	44.68	65.46	110.14
r, 1900	54.18	71.42	125.60
r, 1902	38.52	81.69	120.21
nd September, 1903	45.55	109.70	155.25
904	38.62	105.36	143.98

measurements indicate an irregular but none the less marked e in the natural flowing waters accompanying an equally l increase in the quantity of developed waters. The latter has ade necessary in order that the total supply might be kept up. uses of these shrinkages, which have been thus set forth in etail, are twofold the decreased rainfall of the last decade, e increased development of waters during the same and a pre-period.

The average rainfall at San Bernardino during the last thirty-four years, which may be accepted as typical of the upper valley, has been 15.06 inches. This should be within 2 per cent of the final correct average rainfall for that point. While on the southern slopes and summits of the San Bernardino Mountains the precipitation has been heavier, and in parts of the lowlands more remote from the mountains it has been lighter, the percentages of variation from the normal at any selected point may be safely assumed to be approximately equal to that at San Bernardino. Here, while the general average is 15.06 inches, the average for the last eleven years is 12.14 inches, giving a total deficiency of over 32 inches for that period, and for the last seven years the average has been but 11.36 inches a year. Such a deficiency in a region where all the normal run-off is appropriated at the canyon mouths and only the excess is set free to recharge the gravels that form the underground reservoirs means a proportionately very large reduction in the latter element. And necessarily during years of drought the drain upon the underground supply is greater than during years of normal or excessive rainfall, because during the latter periods several of the winter irrigations may sometimes be omitted, the flowing wells capped, and the pumping plants shut down for a time. Hence, in addition to the decreased supply there have been increased demands on the underground waters during the last ten years, demands independent of the gradual increase in water required by increasing acreage and the greater maturity of groves.

Enterprises like the Bear Valley dam and the suggested reservoir at Filirea Flat, on the upper Santa Ana, although most economical when the region as a whole is considered, necessarily reduce the amount of water available for recharging the gravels below them and thus act unfavorably upon the districts dependent upon the supply in these gravels for irrigation. These dams retain practically all the water which falls above them in their respective drainage basins, so that this supply, instead of escaping during the winter, to be absorbed in large part by the gravels, is stored and used for irrigation, and the underground reservoirs receive only the uncertain amount of return waters from the groves.

In addition to these reductions in the supply through decreased rainfall and developments at the headwaters, there have been many additional wells sunk within the basin for domestic supplies for the growing tributary cities; by the old established companies to maintain the supply necessary to preserve the acreage served by them and to make up for the loss through the shrinkage of surface streams like Warm Creek and the Santa Ana, at one time a prolific source of irrigation water; and by new companies for the reclamation of new tracts.

An attempt to estimate the amount of water which may be taken from the basin without drawing upon the reserve supply is fraught

with difficulties. The amount of water stored in the gravels of the valley is undoubtedly very great. Mr. Lippincott[a] has estimated roughly that their capacity is 6,400,000 acre-feet, an estimate which unquestionably is sufficiently low. This amount, if it could be made available, would supply the canals above Colton for sixty years without the annual additions from rainfall.

As a matter of fact, but a small proportion of it is commercially available. These saturated gravels have been penetrated to depths of over 1,000 feet, and it is estimated that in the center of the valley they may exist at 3,000 feet below the surface. The depth from which water can be pumped at a profit depends upon the value of the crops raised by its use and upon the cost of its distribution. The maximum at present may be accepted as 250 feet, and at this depth certainly less than 20 per cent of the stored waters of the valley could be reached. It is obvious, however, that this water should not be taken out any faster than it is annually restored. The rate of this recharge is a difficult problem.

No definite results can be reached by an attempt to estimate the amount of water which is directly contributed to the basin, since the amounts supplied by rainfall within the valley, or by floods from the mountains, or by seepage through the gravels below the measured surface flows of tributary streams, or by the minor unmeasured canyons about the margin of the basin, or by return waters from irrigated lands which drain back into the valley, must all remain undetermined factors.

By approaching the subject in another way, however, suggestions which appear to be of value result. The Williams and the Neff measurements upon the water plane have already been discussed in part. In each of these the gradient of the decline in water level flattens during the years 1900–1 and 1902–3, until it becomes nearly horizontal. The rainfall during each of these years was more than 17 inches at San Bernardino, where the normal is about 15 inches. If we accept the probable assumption that 2½ inches more than the normal rainfall would check the decline under present conditions of development, and that it might also be checked by reducing the drafts upon the basin by the same percentage, we arrive at the conclusion that about 115 second-feet may be withdrawn without permanently reducing the reserve supply.

Some steps have been taken by the greater irrigating companies, which are dependent upon the underground supplies of San Bernardino Valley, to check the escape of the floods that pass the Bunker Hill dike, in order that more time may be given for their absorption by the porous sand and gravel filling of the basin. Thus far

[a] Lippincott, J. B., Development and application of water near San Bernardino, Cal.: Water-Sup. and Irr. Paper No. 59, U. S. Geol. Survey, 1902, p. 23.

lands and forms an important part of the supply there. This interesting group taps a water supply in the earlier alluvium, a source entirely different from that in which the water at San Bernardino is found. The beds of this older alluvium form the Yucaipe bench, make the hills on either side of San Timoteo Canyon, and extend eastward beyond the area under consideration toward San Gorgonio Pass (fig. 15 and Pl. IX). South of Yucaipe Valley they dip gently northward, the dip increasing in steepness toward the axis of the Badlands ridge which separates San Timoteo Canyon from San Jacinto Valley (fig. 15). This attitude of the beds is due to crustal movements since their deposition. North and east of the Yucaipe they lie horizontal or have slight south and west dips, which may not be structural but only representative of the original depositional slope.

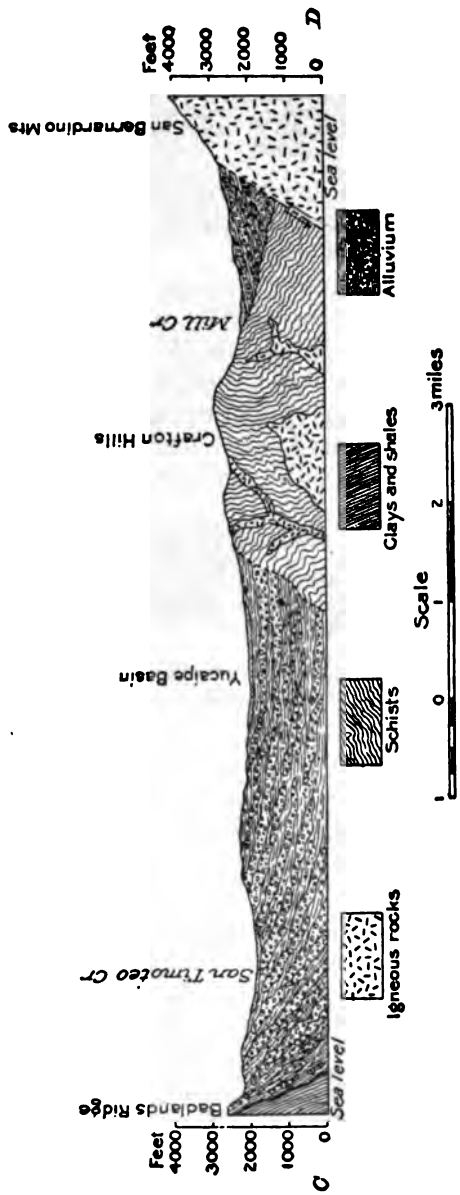


FIG. 15.—Approximate section across the Crafton Hills and Yucaipe Valley along the line C-D, Pl. XII.

The Crafton Hills and the heights on either side of Reservoir Street Canyon are of schistose or igneous bed rock. These two areas are undoubtedly connected, although the connection is buried under alluvium through the lower intervening region. It is probable, too, that the pass between the Crafton Hills and the mountains just east of Mill Creek Canyon is underlain at a moderate depth by bed rock, so that the Crafton Hills mass makes, as it were, a wing dam extending southwest some miles from the San Bernardino Mountains into the alluvial areas. All the streams draining south and west from the hills that separate Mill Creek from the wide valley to the south sink into this old alluvium and percolate slowly through it toward the lower levels.

VIEW OF SAN TIMOTEO CANYON AND THE NORTHWARD-DIPPING EARLIER ALLUVIUM.

They are checked by the Crafton bed-rock mass, and in the vicinity of the mouth of Liveoak Canyon or above meet the northward dips of the alluvium. In the basin thus formed the waters collect under pressure and flow when the porous gravels are tapped by wells. The ordinary overflow from this basin must percolate around the southwestern foot of the Redlands Heights bed-rock area, since its lowest outlet lies in this direction. In the past, after long-continued periods of excessive rainfall, when the Yucaipe gravels had become saturated to higher levels than at present, the canyon through which lies the continuation of Reservoir street toward Yucaipe Valley probably became a spillway. Springs and small areas of peaty land near the head of the canyon are evidences for this hypothesis.

In lower Yucaipe Canyon, a mile or two above its junction with San Timoteo Creek, waters under pressure have been found at depths of several hundred feet. They rise practically to the surface, but do not flow, or flow but little. These waters and those tapped by the Singleton wells in San Timoteo Canyon, as well as those which are the sources of springs in the short northern tributaries of the latter, are probably all supplied from the underground waters gathered in the drainage basin of the upper San Timoteo and its tributaries and percolating along the lines of least resistance toward Santa Ana River. The Crafton Hills bed-rock obstruction and the northern dip of the alluvium south of this obstruction must tend to concentrate the waters in the pervious strata in a relatively narrow zone extending from a short distance south of Bicknell station, on the Southern Pacific, to the vicinity of Redlands Heights. The Redlands wells near the reservoir, and the Redlands Heights wells farther south, are regarded as tapping the principal underground outlet for the drainage area east of Crafton Hills and west of Beaumont. As this area is not large and the precipitation, except on that very small portion of it which forms a part of the slope of the San Bernardino Range, is slight, the waters can not exist in great volume, and so will not bear excessive development. Thus far they seem to have been drawn upon moderately and with excellent judgment.

As has been stated before, the gravels of the earlier alluvium are partially consolidated. They seem, on the whole, to be less pervious than those of later date, and are therefore somewhat inferior in transmission capacity. Because of these two conditions—limited supply and low transmission power—no wells of very great yield have been opened and none are to be expected.

The favorable area for development has been pretty well outlined by the wells which have been bored. It includes the flat valley of the Yucaipe in the vicinity of Dunlaps (Pl. X, A), and the area south of it to the Southern Pacific at El Casco and for a short distance above. Westward it extends to beyond Redlands Heights, which it underlies. Within this area it is expected that wherever porous gravels are

encountered by the drill a fair supply of water will be found. The deeper waters are under pressure, and where the well is started at a low point, as in the bottom of one of the deep arroyos, water may rise nearly to the surface. In wells which are begun on high ground a heavy lift will be necessary. While porous water-bearing gravels are usually found in the well sections, they are less numerous and less certain than in the newer gravels of the valley about San Bernardino. Furthermore, the irregular character of all of this alluvial material precludes the possibility of predicting accurately where coarse gravels are present and where not. Only exploration by the drill can determine this point.

RIVERSIDE BASIN.

Just north of Riverside, in the basin of Spring Brook, four wells have been drilled which yield flowing water, and the springs by which the small stream is fed indicate the probable extension of artesian conditions beyond the area determined by the wells.

A mile or more above the Salt Lake Bridge at Riverside Narrows is a small flowing well which furnishes water for domestic purposes, and other artesian wells now filled, or abandoned for other reasons, are reported from the same vicinity.

At Riverside Narrows Santa Ana River enters a narrow gorge cut in the dioritic bed rock of the region, and the underground waters are forced to or near the surface as they approach this obstruction. In consequence, the river bed, dry for some miles below Slover Mountain, here carries a perennial stream of respectable proportions. The effect of this diorite mass is similar to that produced by the ridge of folded clays which crosses the course of the Santa Ana above Colton and has been discussed as the Bunker Hill dike.

The river wash which has accumulated against the mass is saturated, it contains coarser and finer material in alternating strata, and as these, deposited by the river, slope in the direction of its flow, water entering the coarser members at a higher level farther up the stream is to be found under pressure at a lower level farther down the stream. The waters of the Elliotta, Stansell, and Evans wells above Riverside probably enter the gravels soon after they have passed over the Bunker Hill fold, and their head is only that which accumulates in the few intervening miles. There is little doubt that the water percolates under the High Grove and East Riverside mesas, which are underlain by river alluvium, deposited at a time when the Santa Ana or one of its distributaries flowed through this lowland.

These gravels about Riverside are not generally as coarse as those above the Bunker Hill dike, since they are farther from their origin in the mountains; hence they are somewhat less free water bearers, although excellent in this respect. Flood waters have access to them

A. YUCAIPE VALLEY AND ARTESIAN LANDS.

B. NONARTESIAN WATER-BEARING LANDS IN SANTA ANA VALLEY.

chiefly through the porous wash of the river below Bunker Hill, while the basin above is supplied by the waters absorbed by all of the alluvial fans distributed along the base of the San Bernardino Range.

The Riverside basin is shallower and has a smaller area than the large basin northeast of it, but it has not yet been very heavily drawn upon, and it is benefited by the return waters from a large acreage about Rialto and East Riverside. It should be capable of supplying much larger drafts than have as yet been made upon it, and although the waters thus developed will have to be pumped to the accessible lands, and so will prove more expensive than San Bernardino basin waters now are, the difference in cost may be expected to lessen as the latter waters become more expensive, so that it may soon become financially practicable for the Riverside irrigator to utilize more of these near-by waters and thus reduce the great drafts upon the larger and more important San Bernardino basin.

The city of Riverside is now (1904) installing a domestic system which will utilize a part of these waters. They are to be pumped to a reservoir on Rubidoux Hill and distributed thence to the city mains. Thus used they will augment the supply that now flows by gravity from artesian wells in the San Bernardino basin.

GROUND WATERS.

By ground waters are meant subsurface waters outside the artesian areas (Pls. VII and VIII), which therefore are not found under sufficient pressure to flow by gravity, but become available for irrigation only by means of some sort of pumping device. They have precisely the same origin as the artesian waters—i. e., the rainfall—and, indeed, when they lie above the artesian basin, may later become artesian by passing beneath an impervious cap in the course of their slow movement seaward under the influence of gravity. Below and outside of the basin they constitute the normal subsurface zone of saturation, whose upper limit slopes generally with the soil surface, but at a different rate, so that where the fan material lies high and is open textured it may be hundreds of feet to the ground-water level. This is probably true in the vicinity of Grapeland and some miles southward. Nearer the axis of the valley these waters are nearer the surface and are drawn upon more or less freely for irrigation and for domestic purposes. Their approximate position relative to the surface, where data enough exist for determination, is shown on Pl. VII for the years 1900 and 1904.

West of Lytle Creek the water lies at so low a level and the wells are so few that no attempt has been made to show the position of the water plane, data being entirely insufficient for this purpose.

From a point a mile or more below Crafton eastward the water level seems to have changed but little during the last few years. In a zone immediately surrounding the artesian basin, however, there has been

a distinct change in the water level, a decline varying in amount from zero at the edge of the artesian area to 50 feet in extreme cases some distance back.

On pages 57 and 58 are given tables in which the elevation of the water plane at two periods, four years apart, is shown for a number of wells distributed widely over San Bernardino Valley.

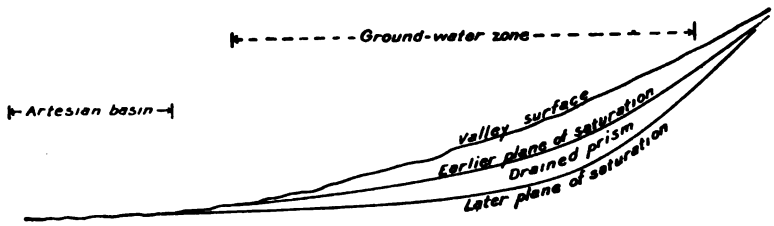


FIG. 16.—Diagrammatic cross section of drained prism in alluvial-fan material.

It is to be noted that the earlier and the present elevations of the water plane are approximately equal at both the upper and the lower edges of the ground-water zone—i. e., the past and the present planes of saturation unite near the artesian limit and again well up the alluvial fans, their most marked divergence being along a median line of the zone, a cross section of the drained prism being thus crescentic in form (fig. 16).

TEMPERATURES.

Waters with temperatures much above the normal are not at all unusual in San Bernardino Valley, nor in other parts of southern California. The region in general is not one of recent volcanic activity, so that, in the majority of cases at least, we have no bodies of fresh intrusive or effusive rock to appeal to as a source of heat. On the other hand, there have been abundant recent dynamic disturbances, as is proved clearly on structural grounds, and the slight earthquakes which occur from time to time suggest that minor movements may be taking place almost constantly along the established fault lines. The enormous friction from these movements must raise the earth temperatures very notably along the lines of disturbance, and the fractured zones adjacent to the faults must sometimes provide easy channels through which surface waters may reach greater depths, become heated, and rise again as hot springs, or through which rock waters with the temperatures of their origin may escape to the surface.

If we consider the distribution of the hot springs we find that, with a few unimportant exceptions, they occur along these definite structural lines, or if we reverse the process and trace the major fault lines we find them marked in many instances by thermal waters.

The most extensive and important group of hot springs is that which issues from crevices in the gneissoid bed rock at the south base of the San Bernardino Range in the vicinity of East Twin Creek Canyon.

THE BUNKER HILL DIKE.

The easternmost group of these is known as the Arrowhead Springs, from the peculiar figure of a gigantic arrow outlined by the vegetation on the mountain side above them. Numerous springs issue here at various temperatures, the highest measured by the writer being 184° F. One-half mile farther west an even greater volume of hot water, estimated at 5 or 10 miner's inches, issues from a number of springs that flow usually from the bowldery alluvium along the lower course of Waterman Canyon (West Twin Creek), but occasionally directly from bed rock. Much of this water has a temperature of 140° or 150°, and even higher as it first issues. A small group of warm springs is found about a mile east of Arrowhead Peak, and in the canyon of the Santa Ana, 2 miles from the edge of the mountains, is another conspicuous warm spring.

The line of disturbance whose western extension is marked by the Bunker Hill fold (Pl. XI) is even more definitely outlined by a series of wells and springs with temperatures above the normal. Within the San Bernardino basin itself a temperature of 72° is found in the mixed waters from three wells pumped into one distributing pipe near the San Bernardino city reservoir. Another well whose waters have a temperature of 90° has been bored about a mile northwest of Bunker Hill and just north of the dike. The latter location is one in which numerous wells of abnormal temperature are found. The "Hobo" well, the Urbita well, and the Topp well, all near Bunker Hill, have temperatures varying from 85° to 105°. Farther eastward a group of shallow wells belonging to the Riverside Water Company, and distributed along the north bank of Santa Ana River, just east of E street extended, have temperatures of 71° to 73°, although less than 100 feet deep in many instances.

Near Loma Linda a number of wells of the Gage canal system discharge waters at temperatures of 70° to 75°, but in these cases the depths are greater, ranging from 320 to 656 feet. Farther east and entirely outside the territory under discussion in this paper, but worthy of mention here because they occur along the same structural line, are the Eden, the Relief, and the Ritchie hot springs, which issue from bed rock near the zone of structural weakness.

This distribution is in itself strong evidence that the heat which is imparted to the underground waters originates, in many cases at least, in the zones of crustal movement, especially the faults, which are a conspicuous feature of the geology of southern California.

Within the San Bernardino Valley lowland, temperatures, except as they are high along the line of the Bunker Hill dike, have a rather erratic distribution. The mean annual atmospheric temperature of the valley is about 62° F., and the ground waters and the waters from the majority of the shallow flowing wells have the normal temperature of 62° to 64°; but at Harlem Springs waters originally issued at vari-

ous temperatures up to 115°. The flowing waters of the Payne well, 642 feet deep, situated 2 miles south of San Bernardino, have a temperature of 112°. The water of the Urbita Springs well has a temperature of 102° to 105°, and other wells which have been mentioned near the Bunker Hill dike exhibit temperatures ranging from 70° to 90°.

When we come to consider temperature gradients—i. e., the number of feet it is necessary to go in depth for each degree rise in temperature from the normal of 62° or 63°—we find such wide extremes as 1° in 3 feet in the "Hobo" well, No. 23, San Bernardino quadrangle, and 1° in 114 feet in one of the Riverside Water Company's deep wells on East Third street. The accompanying table of depths and temperatures illustrates the wide diversity, both in temperatures and in temperature gradients, throughout the valley.

Temperatures in wells in San Bernardino Valley, California.

Number of well.	Depth of well.	Measured temperature at surface.	Theoretical temperature on basis of 1° increase for each 60 feet depth.	Departure from theoretical temperature.	Temperature gradient.
	Feet.	°*F.*	°*F.*	°*F.*	*Feet.*
53	68	71	63	+ 8	8
R 361	68	86	63	+23	3
17	81	73	63	+10	7
252	83	68	63	+ 5	16
18	92	73	64	+ 9	8
23	121	98	64	+ 34	3
8	125	68	64	+ 4	21
125	141	67	64	+ 3	28
123	142	70	64	+ 6	18
124	148	68.5	64	+ 4.5	23
R 330	150	68	65	+ 3	25
234	158	85	65	+ 20	7
328	169	76	65	+ 11	12
126	181	68	65	+ 3	30
R 327	185	80	65	+ 15	10
12[illegible]	190	70	65	+ 5	24
121	196	70	65	+ 5	24
19	225	71	66	+ 5	25
R 329	231	72	66	+ 6	23
R 385	300	115	67	+ 48	6
119	320	73	67	+ 6	29
297	451	90	70	+ 20	16
R 375	460	72	70	+ 2	46
128	472	70	70	0	59
118	482	74	70	+ 4	40
104	506	70	70	0	64

Temperatures in wells in San Bernardino Valley, California—Continued.

Number of well.	Depth of well.	Measured temperature at surface.	Theoretical temperature on basis of 1° increase for each 60 feet depth.	Departure from theoretical temperature.	Temperature gradient.
	Feet.	°*F.*	°*F.*	°*F.*	*Feet.*
[illegible]	517	73	71	+ 2	47
[illegible]	534	74	71	+ 3	44
[illegible]	544	68	71	− 3	91
117	582	74	72	+ 2	49
San Bernardino city well on Antill tract	614	69	72	− 3	88
112	642	112	73	+39	16
115	656	75	73	+ 2	50
315	682	68	73	− 5	114
Urbita new well	740	78	74	+ 4	46
120	784	74	75	− 1	65
Waterman avenue well, Riverside Water Co.	984	75	78	− 3	76

The results can not be accepted rigidly, because in some cases well tubing has been cut at several points and the waters whose temperature is given are therefore mixed waters from undetermined horizons. In one or two other cases the yield of the wells is small, the waters rise but slowly, and sensible changes may therefore have taken place in their passage upward to the surface where the temperatures were measured. But when due allowance is made for these inaccuracies a wide variation remains to be accounted for.

The alternate undisturbed beds of sand, gravel, and clay which fill this valley should exhibit a thermometric gradient which is lower rather than higher than the normal of 1 degree for each 50 or 60 feet increase in depth, which has been established by observations in shafts and deep mines in consolidated rock in various parts of the world. A lower gradient is to be expected, because this alluvium has been deposited recently and with great rapidity, and so may be supposed not to have acquired fully the normal earth temperature. An additional reason for expecting low temperatures is its porosity and the consequent free circulation of meteoric waters, which tend to carry the mean annual temperature of the surface to depths. The low gradients exhibited by the new Antill tract wells of the city of San Bernardino and by the Riverside Water Company's wells Nos. 465 and 315, gradients of 88 to 114 feet per degree, seem to bear out this hypothesis of relatively low temperatures at moderate depths, due to lag in the rise of earth temperatures or to transfer of surface temperatures to depth through the medium of circulating waters. Such low temperatures are to be expected under the conditions which prevail in this basin, but

where higher temperatures are found special explanations seem to be required.

Along the line of the Bunker Hill disturbance the occurrence of high temperatures is fully explained by the known geologic conditions. This ridge represents an anticlinal arch, the strata, which farther north occur at greater depths, being brought near to the surface here by the fold. Hence, the waters percolating along the porous beds at depths near the center of the valley and acquiring the temperatures appropriate to those depths are here found and tapped near the surface as they rise toward the anticline with the inclosing strata.

High temperatures found near the center of the basin, as in the case of the Payne well or more especially the group at Harlem Springs, can not be explained in this way, as they do not occur in connection with anticlinal structures. There are two or three possible explanations for the presence of these hot waters, but sufficient evidence does not exist to decide between them.

Just as springs in the artesian basins represent leakage to the surface through the impervious cap which confines the waters, and as all the water-bearing horizons in the alluvium probably are imperfectly connected by leakage from one horizon to another, so the hot wells and springs found near the middle of the valley may represent similar leakage from near the bottom of the basin to the surface. Again, the occurrence of strong springs of heated waters along the north edge of the valley, as in the case of the Arrowhead group--waters which sink into the alluvium and are reenforced there perhaps by other flows of hot water from near the fault line, flows which pass directly from the heated rocks of the faulted zone into the alluvium without discharging upon the surface at all--at once suggests that it may be these heated waters percolating seaward through the alluvium along rather definite channels which escape as springs at the head of Warm Creek, or are tapped there by comparatively shallow wells. Of these two hypotheses, leakage from near the bottom of the basin to the surface and percolation of hot water from the fault zone toward the center of the basin, the latter seems the more reasonable as an explanation of the Harlem Springs group, while the former is favored as an explanation of the temperature of waters situated like the Payne well, comparatively near the Bunker Hill dike, which forces heated deep waters toward the surface.

CHEMICAL CHARACTER OF THE WATERS.

The waters of the San Bernardino artesian basin are very pure, as the subjoined analyses will show. They are, in effect, mountain waters which have passed for a few miles underground through sands and gravels whose drainage is free, so that they have had little opportunity to dissolve the salts contained in the resistant minerals of the rocks.

Professor Hilgard[a] records three analyses, two from groups of wells in the Gage canal system and a third from Warm Creek, at the mill. The results are as follows:

Analyses of well water, San Bernardino Valley, California.

[In parts per 100,000.]

	Gage system artesian wells.		Warm Creek.
	Group D, No. 5.	Group A, No. 2.	
Sodium chloride (common salt)	0.63	0.91	2.57
Sodium sulphate (Glauber's salt)	1.93	3.13	5.82
Sodium carbonate (sal soda, black alkali)	1.02	.21	2.00
Potassium sulphate	.60	.63	.80
Total soluble residue	4.18	4.88	11.19
Calcium sulphate	.....	.78	1.46
Calcium carbonate	10.17	12.12	7.62
Magnesium carbonate	2.32	2.49	2.53
Silica	2.44	2.39	3.24
Total insoluble residue	14.93	17.78	14.85
Total solids	19.11	22.66	26.04

Dr. A. K. Johnson, of San Bernardino, has furnished the following analysis of waters from the Lytle Creek group of wells, which, until recently, furnished all of the water for the San Bernardino system.

[James A. Shedd, analyst.]

	Parts per 100,000.
Sodium chloride	1.75
Calcium sulphate	1.71
Calcium carbonate	5.56
Magnesium carbonate	3.62
Iron and alumina	1.4
Silica	3.75
Total solids	17.79

The following partial analysis of the warm water (112° F.) from the Payne well is from the California Agricultural Experiment Station, E. W. Hilgard, director:

	Parts per 100,000.
Soluble residue (sodium chloride, sodium sulphate, sodium carbonate, potassium sulphate)	12.56
Insoluble residue:	
Calcium sulphate, calcium carbonate, magnesium carbonate, silica (very small)	22.93
Organic matter and chemically combined water	2.37
Total	37.86

[a] Hilgard, E. W., Subterranean water supply of the San Bernardino Valley: Report of irrigation investigations for 1901, U. S. Dept. Agric., p. 134.

All of these waters are in constant use for irrigation or for domestic purposes, and the small proportion of salts, particularly of the harmful soluble varieties, makes them very desirable for this use.

Professor Hilgard points out that both the Gage canal and the Warm Creek waters contain percentages of the fertilizing potassium sulphate which are unusual in ground waters and amount to 47 and 63 pounds per acre, respectively, on the basis of a duty of 1 miner's inch to 5 acres. In the other analyses the potash was not separately determined.

The hot wells and springs of the valley are very generally utilized for baths or medicinal purposes in connection with health resorts. Some complete and partial analyses are available which illustrate their character.

Mr. F. M. Coulter, of Los Angeles, has furnished the following analysis of water from one of the Arrowhead Springs:

Analysis of water from Arrowhead Springs, California.

[E. W. Hilgard, analyst.]	Parts per 100,000.
Sodium chloride (common salt)	14.148
Sodium sulphate (Glauber's salt)	73.483
Potassium sulphate	6.922
Calcium sulphate	2.323
Magnesium sulphate	.253
Calcium carbonate	2.323
Magnesium carbonate	.555
Lithium	Trace.
Borine	Trace.
Strontium	Trace.
Silica	8.550
Organic matter	Trace.
Total solids	108.557
Free sulphureted hydrogen, cubic inch per gallon	.622

The appended analysis, also made under Professor Hilgard's direction, illustrates the character of the water from the Urbita Hot Springs, near San Bernardino:

Analysis of water from Urbita Springs, California.

	Parts per 100,000.
Sodium chloride	3.2
Sodium sulphate, Potassium sulphate (small amount),	20.4
Sodium carbonate	7.40
Calcium sulphate, Calcium and magnesium carbonate,	1.5
Silica	1.0
Chemically combined water, etc	8.00
Total	41.5

An old analysis of the Harlem Springs water, accredited to Professor Woodbridge, of Pasadena, shows the following solids present:

Analysis of water from Harlem Springs, California.	Parts per 100,000.
Sodium chloride	3.89
Sodium sulphate	14.36
Potassium sulphate	Trace.
Sodium carbonate	3.20
Calcium carbonate, etc	4.47
Silica	3.15
Total	29.07

The large proportion of the laxative medicinal salt, sodium sulphate (Glauber's salt), in all these hot waters is worthy of note.

TABLES OF FLOW.

For a number of years measurements of stream flow and of the amounts of water carried in the various canals of San Bernardino Valley have been made by the United States Geological Survey and by engineers engaged in private practice. The results have been published from time to time in the water-supply papers of the Survey, but for convenience of reference those which are of greatest importance to water users in the valley are assembled in the tables that follow:

MILL CREEK.

Discharge measurements of Mill Creek at headworks of Crafton canal, San Bernardino County, Cal..

Date.	Hydrographer.	Discharge.
		Second-feet.
July 29, 1896	J. H. Quinton	14.2
April 12, 1898	J. B. Lippincott	15.7
April 29, 1898	do	18.9
June 12, 1898	do	18.1
July 23, 1898	do	11.8
September 8, 1898	do	13.1
October 18, 1898	F. H. Olmsted	15.3
November 9, 1898	do	15.2
December 8, 1898	do	12.6
January 12, 1899	S. G. Bennett	10.8
February 18, 1899	do	10.4
March 23, 1899	do	15.6
May 6, 1899	do	14.6
May 31, 1899	do	11.6
June 15, 1899	do	6.8
July 15, 1899	do	7.4

Discharge measurements of Mill Creek at headworks of Crafton canal, etc.—Continued.

Date.	Hydrographer.	Discharge.
		Second-feet.
July 27, 1899	S. G. Bennett	4.3
August 24, 1899	do	[a] 5.7
August 24, 1899	do	[b] 1.5
April 14, 1900	do	10.8
May 5, 1900	do	[a] 39.0
May 5, 1900	do	[c] 8.0
July 13, 1900	do	[a] 5.4
July 13, 1900	do	[b] 3.4
October 2, 1900	W. W. Cockins, jr	[d] 8.6
March 30, 1901	S. G. Bennett	20.0
July 6, 1901	do	23.3
December 5, 1901	do	14.5
April 5, 1902	do	15.7
April 5, 1902	do	[a] 5.4
May 31, 1902	do	19.2
July 10, 1902	do	10.8
September 3, 1902	W. B. Clapp	5.3
November 5, 1902	S. G. Bennett	12.3
April 1, 1903	W. B. Clapp	1,280
April 24, 1903	W. B. Clapp and J. C. Clausen	39
May 16, 1903	W. B. Clapp	68
June 9, 1903	do	46
July 1, 1903	do	29
September 1, 1903	do	22
March 22, 1904	W. B. Clapp and E. C. Murphy	17.6
September 21, 1904	W. B. Clapp	14.1
November 11, 1904	E. C. La Rue	11.2

[a] In creek.
[b] Pumped.
[c] Canal.
[d] Of which 1.35 second-feet is pumped.

SANTA ANA RIVER.

charge measurements of Santa Ana River and canal at Warm Spring, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
e 20, 1896	J. B. Lippincott	80.05
28, 1896	J. H. Quinton	74.70
ember 21, 1896	J. B. Lippincott	35.18
ary 27, 1897	do	47.58
h 4, 1897	do	105.70
15, 1897	do	82.74
1, 1897	A. Q. Campbell	90.79
6, 1897	do	71.37
st 8, 1897	do	74.96
mber 30, 1897	do	65.48
mber 14, 1897	do	47.21
ry 8, 1898	do	34.28
9, 1898	A. H. Crowe	50.82
11, 1898	J. B. Lippincott	39.28
29, 1898	do	42.33
12, 1898	do	39.06
3, 1898	do	47.56
nber 8, 1898	do	36.67
er 18, 1898	F. H. Olmsted	30.70
nber 9, 1898	do	21.78
ber 8, 1898	do	24.74
ry 12, 1899	S. G. Bennett	38.00
ary 18, 1899	do	32.04
23, 1899	do	37.22
, 1899	do	29.24
1, 1899	do	22.10
15, 1899	do	19.80
5, 1899	do	25.90
7, 1899	do	23.55
t 24, 1899	do	10.86
14, 1900	do	22.66
, 1900	do	24.40
3, 1900	do	22.30
nber 20, 1900	do	102.00
nber 22, 1900	do	[a] 15.64
ary 5, 1901	do	101.00
ary 23, 1901	do	110.00
4, 1901	do	102.00

[a] Calculated.

Discharge measurements of Santa Ana River and canal at Warm Spring, etc.—Continued

Date.	Hydrographer.	Discharge.
		Second-feet.
March 30, 1901	S. G. Bennett	44.6
July 6, 1901	do	39.3
August 20, 1901	do	30.7
October 8, 1901	do	45.2
April 5, 1902	do	55.2
May 31, 1902	do	29.0
July 10, 1902	do	23.5
September 3, 1902	W. B. Clapp	24.2
November 5, 1902	S. G. Bennett	18.0
February 6, 1903	W. B. Clapp	40
April 1, 1903	do	4,906
April 2, 1903	do	1,068
April 3, 1903	do	565
April 24, 1903	W. B. Clapp and J. C. Clausen	132
May 16, 1903	W. B. Clapp	95
June 30, 1903	do	56
August 31, 1903	do	41
November 24, 1903	do	26
January 29, 1904	do	26
March 4, 1904	do	33
March 12, 1904	do	43
March 22, 1904	W. B. Clapp and E. C. Murphy	39
April 20, 1904	W. B. Clapp	68
April 21, 1904	do	59
May 14, 1904	do	36
May 28, 1904	do	39
June 29, 1904	do	46
September 21, 1904	do	58
November 11, 1904	do	19

PLUNGE CREEK.

Discharge measurements of Plunge Creek at the headworks in the canyon, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
June 12, 1898	J. B. Lippincott	2.30
September 9, 1898	do	.20
March 25, 1899	S. G. Bennett	10.90
August 25, 1899	do	.50
July 12, 1900	do	.34
April 7, 1902	do	12.40
September 4, 1902	W. B. Clapp	.37
April 23, 1903	W. B. Clapp and J. C. Clausen	23.00
May 17, 1903	W. B. Clapp	9.00
September 11, 1903	do	.60
September 21, 1904	do	.60

CITY CREEK.

Discharge measurements of City Creek at mouth of canyon, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
June 11, 1898	J. B. Lippincott	3.03
September 9, 1898	do	.07
March 25, 1899	S. G. Bennett	8.80
August 25, 1899	do	.17
July 12, 1900	do	.16
October 1, 1900	W. W. Cockins, jr	.21
April 7, 1902	S. G. Bennett	12.5
September 4, 1902	W. B. Clapp	.2
April 23, 1903	W. B. Clapp and J. C. Clausen	22.00
May 17, 1903	W. B. Clapp	11.2
September 11, 1903	do	.2
September 22, 1904	do	.5

EAST TWIN CREEK.

Discharge measurements of East Twin Creek in canyon, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
June 11, 1898	J. B. Lippincott	2.06
September 9, 1898	do	.73
March 24, 1899	S. G. Bennett	4.38
August 25, 1899	do	.74
July 12, 1900	do	.77
October 1, 1900	W. W. Cockins, jr	.57
April 4, 1902	S. G. Bennett	4.9
September 4, 1902	W. B. Clapp	.4
April 23, 1903	W. B. Clapp and J. C. Clausen	10.0
May 17, 1903	W. B. Clapp	4.8
September 11, 1903	do	.4
September 22, 1904	do	.6

WEST TWIN CREEK.

Discharge measurements of West Twin Creek in Waterman Canyon, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
June 11, 1898	J. B. Lippincott	2.14
September 9, 1898	do	.38
March 21, 1899	S. G. Bennett	3.00
August 21, 1899	do	.20
July 12, 1900	do	.22
October 1, 1900	W. W. Cockins, jr	.16
April 4, 1902	S. G. Bennett	3.20
September 4, 1902	W. B. Clapp	.13
April 23, 1903	W. B. Clapp and J. C. Clausen	8.6
May 18, 1903	W. B. Clapp	4.4
September 11, 1903	do	.30
September 21, 1904	do	.40

LYTLE CREEK.

The following measurements were made by A. H. Koebig and G. O. Newman in connection with suits in which the title to the water supply of this creek was involved:

Discharge measurements of Lytle Creek at mouth of canyon, San Bernardino County, Cal.

Date.	Discharge.	Date.	Discharge.
	Second-feet.		*Second-feet.*
June 3, 1892	35.58	August 19, 1894	11.44
September 20, 1892	18.70	August 25, 1894	12.32
September 30, 1892	22.04	October 3, 1894	16.20
October 28, 1892	20.64	September 2, 1895	56.10
November 21, 1892	22.04	September 30, 1895	40.78
November 27, 1892	20.68	March 3, 1896	18.08
September 7, 1893	49.20	April 23, 1896	19.14
September 18, 1893	49.20	April 24, 1896	18.60
September 25, 1893	46.34	April 25, 1896	20.52
October 4, 1893	45.30	May 3, 1896	18.52
June 6, 1894	17.96	May 4, 1896	17.26
June 8, 1894	15.50	May 10, 1896	18.16
July 10, 1894	13.22	May 25, 1896	15.32
July 11, 1894	13.22	May 26, 1896	12.84
July 25, 1894	13.36		

The following measurements were made by the United States Geological Survey:

Discharge measurements of Lytle Creek at mouth of canyon, San Bernardino County, Cal.

Date.	Hydrographer.	Discharge.
		Second-feet.
July 24, 1896	J. H. Quinton	15.7
June 10, 1898	J. B. Lippincott	10.7
August 27, 1898	F. H. Olmsted	10.0
August 29, 1899	S. G. Bennett	12.5
June 8, 1900	do	6.2
September 29, 1900	W. W. Cockins, jr	4.6
April 4, 1902	S. G. Bennett	19.9
September 5, 1902	W. B. Clapp	5.0
April 1, 1903	do	1,790.0
April 22, 1903	W. B. Clapp and J. C. Clausen	63.0
May 19, 1903	W. B. Clapp	29.5
July 2, 1903	do	16.5
September 12, 1903	do	14.7
September 22, 1904	do	9.2

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ative amounts of water, in second-feet, flowing in canals above Colton—Continued.

ame of ditch.	1898.		1899.			1900.			Sept., 1902.	Aug. and Sept., 1903.	1904.	
	June.	Sept.	Mar.	June.	Aug.	Mar.	June.	Sept.			May and June.	Aug.
le Water Co. (up-nal)	59.04	61.34	60.53	53.92	52.04	61.94	52.94	61.02	47.97	55.90	42.40	38.13
pumping plant	.....	.....	.....	.....	.....	.....	.....	.....	4.38	4.44	.....	.....
e Water Co.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.60	.50
stout ditch	2.30	2.08	2.23	1.13	.90	.51	.40	.16	.00	.....	.....	.....
ditch	1.00	1.02	.85	.77	.69	.70	.89	.86	.93	.42	.51	.47
Warren ditch	2.32	2.32	3.09	.62	1.56	2.55	1.70	.53	1.88	1.61	.....	.....
verside 350-inch g plant	.....	.....	.....	.....	.....	.....	.....	.....	5.94	3.41	6.52	5.35
ditch	.26	.01	.76	.25	.01	1.12	.13	.00	.00	.....	.....	.....
ditch	.34	.38	.47	.28	.09	.23	.00	.00	.00	.....	.....	.....
ft tract artesian	.....	.....	.....	.....	.....	.....	.....	.....	.....	.23	.....	.....
l	138.11	144.69	146.44	132.11	110.14	131.46	117.41	125.61	120.21	155.25	123.24	127.86

LIST OF WELLS.

ater-Supply Paper No. 60, Mr. J. B. Lippincott published lists nost important of the wells in the Redlands and San Bernar-adrangles. The edition of this paper was exhausted soon after e; therefore the lists are here republished. No attempt has ade to revisit all wells or to secure complete revised data r levels and yield, and such evidence as has been secured on of these points appears in Pl. VII and in the tables on pages 58. The data, therefore, as they are published here, represent ns as they existed in 1900.

CANALS ABOVE COLTON.

Comparative amounts of water, in second-feet, flowing in canals above Colton.

[K. Sanborn, observer.]

Name of ditch.	1898.		1899.			1900.			Sept., 1902.	Aug. and Sept., 1903.	1904.	
	June.	Sept.	Mar.	June.	Aug.	Mar.	June.	Sept.			May and June.	Aug.
Barnhill pumping plant										0.80	0.85	0.77
Beam ditch	0.67	0.65	0.72	0.52	0.40	0.68	0.50	0.33	0.22	.08	.02	.00
Bloomington pumps	5.26	5.49	(a)	5.93	3.05	3.80	3.68	3.28	.00	8.82	.00	5.61
Brown tract—artesian well										.11		
Camp Carlton ditch	.61	1.20	2.13	1.62	1.02	2.55	2.60	1.67	1.70	2.20	2.50	2.60
Carr pumping plant												.72
City of Colton (total all pumps)	6.82	7.40	3.20	5.49	3.89	4.94	3.21	3.54	3.53	3.17	3.00	2.06
City of San Bernardino											2.69	2.81
Colton Terrace Water Co.	1.97	1.61	1.69	1.30	1.30	1.69	1.54	1.53	1.08		.34	.34
Cooley tract—artesian wells										2.70		
Daly ditch	.63	.67	.71	.51	.51	.72	1.12	.54	.00			
Gage canal:												
Diversion	1.16	1.16	.72	.24	.64	.39	.29	.17	.00			
Palm avenue	26.26	25.07	26.68	25.22	23.47	21.96	22.23	27.85	30.17	30.82	27.80	31.96
Garner tract—artesian well										.77		
Haws & Talmage ditch	.84	.00	.28	.00	.00	.00	.00	.00	.00			
Hunter pumping plant										1.79	.82	1.54
Hurd tract—artesian wells										.21		
Johnson & Hubbard (pumping plant)										.42	.67	.39
Lamb pumping plant										.24	.24	.25
Lawson Well Co.										.59	.65	.50
Logsdon & Farrell ditch	.72	.63	1.61	1.15	.54	1.26	.49	.20	.00			
Lytle Creek Water and Improvement Co.												4.00
McIntyre ditch	.37	.04	.82	.15	.00	.14	.01	.00	.00			
McKenzie ditch	2.54	2.08	9.40	3.86	2.00	2.30	1.57	1.69	.00	.00	.67	.58
Meeks & Daly ditch	8.42	17.00	17.00	15.48	10.45	13.94	13.78	14.68	13.40	12.87	16.30	16.75
Merryfield pumping plant											.90	.80
Mount Vernon Water Co.											91	.91
Orange Land and Water Co.										1.08	1.14	1.12
Rabel Dam ditch	5.37	3.07	2.36	1.54	.94	.54	.35	.07	.00			
Ranchero pumping plant	1.75	1.64	1.64	1.00	.41	.24	.55	1.33	2.28	1.09	1.46	1.30
Riverside Highlands Water Co. (Lytle Creek)	4.40	4.43	1.25	2.08	2.00	6.59	5.38	3.70		8.98	7.92	2.00
Riverside Highlands Water Co. (Santa Ana River)												6.85
Riverside Water Co. (Flume Pump No. 1)									5.03	4.08	.79	2.99
Riverside Water Co. (Flume Pump No. 2)										2.63	1.76	2.52
Riverside Water Co. (mill flume)	3.12	3.36	5.30	7.29	2.56	2.67	2.17	.94	.50	.00	2.68	.00
Riverside Water Co. (mill pump)	1.94	2.04	(a)	1.77	1.67	(a)	1.88	1.52	1.20		1.32	1.38
Riverside Water Co. (River Ditch Pump No. 1)											5.47	4.92
Riverside Water Co. (River Ditch Pump No. 2)										5.79	3.86	4.22

a Pumps not run.

Comparative amounts of water, in second-feet, flowing in canals above Colton—Continued.

Name of ditch.	1898.		1899.			1900.			Sept., 1902.	Aug. and Sept., 1903.	1904.	
	June.	Sept.	Mar.	June.	Aug.	Mar.	June.	Sept.			May and June.	Aug.
Riverside Water Co. (upper canal)	59.04	61.34	60.53	53.92	52.04	61.94	52.94	61.02	47.97	55.90	42.40	38.13
Rogers pumping plant	.....	.....	.....	.....	.....	.....	.....	.....	4.38	4.44	.....	.....
Rosedale Water Co.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.60	.50
Shay & Stout ditch	2.30	2.08	2.23	1.13	.90	.51	.40	.16	.00	.....	.....	.....
Swamp ditch	1.00	1.02	.85	.77	.69	.70	.89	.86	.93	.42	.51	.47
Ward & Warren ditch	2.32	2.32	3.09	.62	1.56	2.55	1.70	.53	1.88	1.61	.....	.....
West Riverside 350-inch pumping plant	.....	.....	.....	.....	.....	.....	.....	.....	5.94	3.41	6.52	5.35
Whiting ditch	.26	.01	.76	.25	.01	1.12	.13	.00	.00	.....	.....	.....
Whitlock ditch	.34	.38	.47	.28	.09	.23	.00	.00	.00	.....	.....	.....
Wozencraft tract artesian well	.....	.....	.....	.....	.....	.....	.....	.....	.....	.23	.....	.....
Total	138.11	144.69	146.44	132.11	110.14	131.46	117.41	125.61	120.21	155.25	123.24	127.86

LIST OF WELLS.

In Water-Supply Paper No. 60, Mr. J. B. Lippincott published lists of the most important of the wells in the Redlands and San Bernardino quadrangles. The edition of this paper was exhausted soon after its issue; therefore the lists are here republished. No attempt has been made to revisit all wells or to secure complete revised data on water levels and yield, and such evidence as has been secured on the first of these points appears in Pl. VII and in the tables on pages 57 and 58. The data, therefore, as they are published here, represent conditions as they existed in 1900.

Wells in Redlands quadrangle.

[*Abbreviations used in well records.*—Under "Method of lift:" Hand=hand pump. Horse=horsepower machine. Electric=an electric motor. Centrifugal=a centrifugal pump. Gas=a gasoline engine. Wind=a windmill. 14 wind=that water is pumped by a 14-foot windmill. In case of the gasoline engines, electric motors, etc., the accompanying figures indicate the horsepower. Under "quantity of water:" Good indicates a good supply of water. Small indicates a small or deficient supply of water.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
1	Doctor Meeker	Sec. 16, T. 1 S., R. 2 W.	1900	Dug, 4 by 6 foot	1,995	1,718	130		$1,100			
2	Ward, Mills & Co.	Sec. 21, T. 1 S., R. 2 W.	1900	do	2,005	1,933	125	Gas	750			
3	Crafton Water Co.	Sec. 7, T. 1 S., R. 1 W.	1900	Dug, 5 by 6 foot	3,010	2,992	132	Centrifugal; electric	2,000	$2,500	1.38	Irrigation.
4	do	Sec. 8, T. 1 S., R. 1 W.	1900	Dug, 5½ by 6½ foot.	3,650	3,648	93	do	a 6,000	2,500	2.70	Do.
5	Mrs. M. A. Brown	Sec. 22, T. 1 S., R. 2 W.	1879	Dug, 4 by 4 foot	2,250	2,225	27	Wind		100		Domestic.
6	Geo. McIntosh	do	1899	do	2,230	2,189	70	Centrifugal; electric				Irrigation.
7	R. P. McIntosh	Sec. 20, T. 1 S., R. 2 W.	1900	Dug, 4½ by 4½ foot.	1,910	1,818	103	Cylinder pump; gas	700	925	.14	Do.
8	L. Lodge	Sec. 16, T. 1 S., R. 2 W.	1900	Dug, 4 by 6 foot	2,060	2,050	70	do		1,500	.30	Do.
9	L. Lyons	do	1900	do	2,075	2,052		do				Do.
10	T. P. Christian	Sec. 17, T. 1 S., R. 2 W.	1900	do	1,900	1,748	180	do		1,500		Do.
11	F. Wieder	Sec. 29, T. 1 S., R. 2 W.	1900	Dug, 4 by 5 foot	1,830	1,779	100	do	450	950		Do.
12	E. J. Roberts	Sec. 28, T. 1 S., R. 2 W.	(b)	Dug, 4 by 6 foot	2,200	2,192		Horse	300			Do.
13	H. H. Garstin	Sec. 29, T. 1 S., R. 2 W.	1900	Bored, 10-inch	2,000	1,905	241	Cylinder pump; gas	800	1,430	.06	Do.
14	W. J. Tench	Sec. 19, T. 1 S., R. 2 W.		Dug, 4 by 6 foot	1,720	1,560	163					Irrigation; domestic.
15	East Redlands Water Co.	Sec. 36, T. 1 S., R. 3 W.	1900	Bored, 12-inch	1,805	1,621	514	Cylinder pump; gas	2,200		.32	Irrigation.
16	E. & D. Conkling	Sec. 31, T. 1 S., R. 2 W.	1899	Bored, 10-inch	1,795	1,545	350	do		2,200	.40	Do.
17	M. S. Crosswell	Sec. 24, T. 1 S., R. 3 W.		Dug, 4 by 6 foot	1,540	1,378	163	do			.12	Do.
18		Sec. 33, T. 1 S., R. 2 W.		Dug, 2½ by 4 foot	2,120	2,060	60					
19	Mr. Gregory	do	1892	Dug	2,130	2,123	10	Hand	20			Domestic.
20	Dunlap estate	Sec. 4, T. 2 S., R. 2 W.	1899	Bored, 10-inch	2,040	2,040		Centrifugal; gas			.50	Irrigation.
21	do	do	1895	Bored, 7-inch	2,075	2,077	142	Artesian			.005	Domestic.
22	do	do	1900	Bored, 10-inch	2,100	2,100	800	do	2,950		.015	Irrigation.
23	do	do	1900	do	2,090	2,090		do				Do.

24	Houghton & McNee	do	1896	Dug, 3 by 4 foot	2,270	2,227	43	Wind					Domestic.
25	Geo. Clyde (tunnel)	Sec. 26, T. 1 S., R. 2 W.		Hydraulic, 4 by 6 foot.	2,700	2,700	97	Gravity	c 300		.02		Irrigation; domestic.
26	Mr. Biggin	Sec. 34, T. 1 S., R. 2 W.	1899	Dug, 6 by 6 foot	2,224	2,163	65				.16		
27	South Mountain Water Co.	Sec. 33, T. 1 S., R. 2 W.	1900	Bored, 10-inch	2,160	2,132	965+	Centrifugal; steam					Irrigation.
28	Garland estate	Sec. 25, T. 1 S., R. 3 W.	1900	do	1,570	1,394		Cylinder pump; gas					Do.
29	C. D. Fowler	Sec. 5, T. 1 S., R. 3 W.	1891	do	1,180	1,125	70						
30	West Redlands Water Co.	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 12-inch	1,600	1,530	226	Cylinder pump; gas	1,250	2,500	.40		Do.
31	do	do	1899	Bored, 10-inch	1,620	1,529	248		1,080				Do.
32	do	do	1899	Bored, 12-inch	1,626	1,536	243	Cylinder pump; gas	1,700	2,500	.36		Do.
33	Redlands Heights Water Co.	Sec. 1, T. 2 S., R. 3 W.	1900	Bored, 10-inch	1,880		300		1,200				Do.
34	Mr. Painter (?)	Sec. 8, T. 2 S., R. 2 W.	1899	Dug, 4 by 6 foot	1,975	1,932	60						
35	do	do	1899	do	1,975	1,932	46						
36	Mrs. Diaz	Sec. 14, T. 2 S., R. 3 W.		Bored, 7-inch	1,545	1,456	96	Hand	125	20			Domestic.
37	C. W. Blue	do	1898	do	1,523	1,455	110	Wind	200	75			Domestic; irrigation.
38	A. Gregory	Sec. 27, T. 1 S., R. 3 W.	1895	do	1,379	1,274	168	do	250	500	.016		Domestic.
39	W. McConkey	do	1898	do	1,380			do					Do.
40	D. Madell	do	1898	do	1,377	1,277	171	do	274		.001		Do.
41	G. H. Garland	Sec. 26, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,450	1,261	246	Cylinder pump; gas		3,000	.40		Irrigation.
42	C. L. Hayes	Sec. 27, T. 1 S., R. 3 W.	1899	do	1,420	1,270	428	do	850	1,400	.30		Do.
43	O. W. Harris	Sec. 34, T. 1 S., R. 3 W.	1895	Bored, 7-inch	1,503	1,303	312	Cylinder pump; electric.	600	800	.075		Do.
44	Horace Evans	Sec. 33, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,455	1,259	660	Cylinder pump; gas	1,900	1,400	.18		Irrigation; domestic.
45	A. C. Fowler	Sec. 32, T. 1 S., R. 3 W.	1898	Bored, 9-inch	1,250	1,140	170	do	250	300	.10		Irrigation.
46	L. C. Smith	do	1898	Dug, 3 by 3 foot	1,215	1,135	83	Wind	90	65	.003		Domestic.
47	P. B. Fussell	do	1897	Bored, 12-inch	1,253	1,195	165	do	330	230			Irrigation; domestic.
48	E. Vache	do	1885	Bored, 7-inch	1,260	1,200	140	do	170	75			Domestic.
49		Sec. 4, T. 2 S., R. 3 W.	1893	do	1,350	1,290	150	do					Stock.
50	W. D. Covington	do	1893	do	1,325	1,290	157	Hand	350	20	Small.		Do.
51	do	do	1893	Bored, 10-inch	1,300	1,300	750	Artesian	2,000		.002		Domestic; stock.
52	D. S. Jordan	do	1899	Bored, 7-inch	1,395	1,379	56	Wind	80	90	.001		Domestic; irrigation.

a Well and tunnel 250 feet long. b Not completed. c Tunnel 97 feet long.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
53	Redlands Domestic Water Co.	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,560	1,503	.....	Centrifugal; electric	$1,800	.....	0.80	Domestic; irrigation.
54	Wood, Bill & Davis	Sec. 33, T. 1 S., R. 3 W.	1899	do	1,305	1,225	462	Cylinder pump; gas	1,200	$1,800	.40	Do.
55	D. H. Gillan	Sec 32, T. 1 S., R. 3 W.	1899	Bored, 8-inch	1,245	1,157	438	Air compressor; gas	.....	3,000	.50	Do.
56	H. Bermudas	do	1893	Bored, 7-inch	1,210	1,156	112	Hand	.....	3	.....	Domestic.
57	N. B. Hinckley estate	do	.....	Bored, 10-inch	1,177	1,021	700+	Wind	.....	.....	.....	Domestic; irrigation.
58	Wm. Curtis	Sec. 30, T. 1 S., R. 3 W.	1885	do	1,144	1,076	76	do	150	100	.002	Domestic.
59	E. C. Curtis	Sec 29, T. 1 S., R. 3 W.	1895	Bored, 7-inch	1,120	1,070	96	do	160	75	.002	Do.
60	R. T. Curtis	do	1895	do	1,123	1,073	86	do	140	100	.003	Do.
61	W. M. Curtis	do	1899	Bored, 12-inch	1,125	1,079	415	Cylinder pump; gas	900	1,800	.70	Irrigation.
62	N. B. Curtis	do	1895	Bored, 7-inch	1,126	1,076	84	Wind	140	60	.001	Domestic.
63	N. B. Hinckley estate	Sec. 30, T. 1 S., R. 3 W.	1899	Bored, 36-inch Bored, 11-inch	1,150	1,103	65 271	Centrifugal; gas	900	800	.42	Irrigation.
64	L. & M. Frink	do	1889	Bored, 7-inch	1,140	1,112	62	Wind	100	163	.....	Domestic.
65	Mrs. P. S. Stewart	do	1898	do	1,144	1,109	76	do	150	65	.001	Do.
66	Gansnor & Renwick	do	1898	do	1,140	1,110	200	do	320	90	.003	Domestic; irrigation.
67	Redlands Water Co	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,563	.....	.....	Centrifugal; electric	.....	.....	.....	Irrigation.
68	Mrs. M. Robison	Sec. 30, T. 1 S., R. 3 W.	1870	Dug, 3-foot	1,110	.....	24	Hand	.....	.....	Dry.	
69	Southern Pacific R. R. Co.	Sec. 31, T. 1 S., R. 3 W.	1890	Bored, 7-inch	1,176	1,116	75	do	145	20	.....	Domestic.
70	W. F. Whittier	do	1898	Bored, 10-inch Bored, 7-inch	1,410	1,208	294 212	Cylinder pump; gas	1,000	985	.14	Domestic; irrigation.
71	do	do	1898	Bored, 14-inch Bored, 10-inch	1,150	1,108	276 84	Force pump; gas	1,020	.....	.80	Irrigation.
72	Owen Buchanan	do	1898	Bored, 7-inch	1,265	1,149	237	Cylinder pump; gas	379	800	.14	Do.
73	W. J. Lawrence	do	1898	do	1,230	1,143	190	do	304	700	.12	Do.

74	Frink Bros.			Bored, 10-inch								.02	Do.
75	Rhoda Wilson	do	1899	Bored, 7-inch	1,138		59	Wind	95	65	.001	Domestic.
76	D. Van Leuven	do	1900	Bored, 9-inch	1,132	1,098	63	Hand	65	14		Do.
77	E. Hankins	Sec. 28, T. 1 S., R. 3 W.	1899	Bored, 12-inch	1,254	1,200	290	Cylinder pump; gas	800	1,300	.40	Irrigation; domestic.
78	J. A. Osborn	do	1899	Bored, 10-inch	1,225	1,173	320	Centrifugal; gas	880		.50	Do.
79	do	do		Bored, 7-inch	1,224	1,174	190	Wind	300	72	.001	Domestic.
80	Mrs. S. W. Sylvera	Sec. 29, T. 1 S., R. 3 W.	1891	do	1,200	1,170	90	do		80	.001	Do.
81	A. B. Cook	do	1897	Bored, 10-inch	1,206	1,166	110	Centrifugal; gas	220	800	.40	Domestic; irrigation.
82	S. Mansfield	do	1900	do	1,195	1,163	340					
83	do	do	1890	Bored, 7-inch	1,193	1,154	109	Wind	175		Small.	Do.
84	A. Lenanon	do	1895	do	1,186	1,156	130	Cylinder pump; horse	208	40		Domestic.
85	John Furney	do	1890	do	1,179	1,139	60	Wind	100	150	.003	Domestic; irrigation.
86	Barton Land and Water Co.	do	1891	do	1,180	1,137	63	Hand	100			Domestic.
87	M. D. Easton	do	1890	do	1,121	1,101	45	Wind	80	70	.003	Do.
88	Barton Land and Water Co.	do	1891	do	1,130	1,100	48	Hand				Do.
89	J. R. Campbell	do	1893	do	1,190	1,155	103	do	190	25		Do.
90	Carl Furst	do	1891	Bored, 5¼-inch	1,215	1,180	114	do	165	35		Do.
91	S. E. Rockwell	do	1900	Bored, 10-inch	1,200	1,170	356	Cylinder pump; gas	1,000	860	.34	Irrigation.
92	J. Hickey	do	1898	Bored, 9¼-inch	1,226	1,190	152	do	314	700	.20	Irrigation; domestic.
93	B. M. James	do	1899	Bored, 10-inch	1,230	1,198	220	do	418	900	.34	Do.
94	W. A. Nichols	Sec. 28, T. 1 S., R. 3 W.	1891	Bored, 7-inch	1,246	1,194	122	Hand				Domestic.
95	do	do		Bored, 10-inch	1,255	1,206	284	Cylinder pump; gas	530	1,000	.36	Irrigation.
96	W. D. Tobey	Sec. 29, T. 1 S., R. 3 W.		do	1,204		324	do				Do.
97	S. A. Grover	Sec. 28, T. 1 S., R. 3 W.	1899	do	1,253	1,183	231	do	700	1,100	.40	Domestic; irrigation.
98	Schee Bros.	do	1899	do	1,280	1,210	425	do	1,400	1,500	.50	Do.
99	W. F. Schee	do	1894	Bored, 7-inch	1,291			do				Irrigation.
100	Redlands Water Co	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,565			Centrifugal; steam			1.56	Do.
101	Barton Land and Water Co.	Sec. 28, T. 1 S., R. 3 W.	1900	do	1,315	1,225	250					
102	Willis Miller	Sec. 21, T. 1 S., R. 3 W.	1893	Bored, 7-inch	1,290	1,203	123	Wind	200	125	.002	Domestic.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
53	Redlands Domestic Water Co.	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,560	1,503	.....	Centrifugal; electric	$1,800	.....	0.80	Domestic; irrigation.
54	Wood, Bill & Davis	Sec. 33, T. 1 S., R. 3 W.	1899	do	1,305	1,225	462	Cylinder pump; gas	1,200	$1,800	.40	Do.
55	D. H. Gillan	Sec 32, T. 1 S., R. 3 W.	1899	Bored, 8-inch	1,245	1,157	438	Air compressor; gas	.....	3,000	.50	Do.
56	H. Bermudas	do	1893	Bored, 7-inch	1,210	1,156	112	Hand	.....	3	.....	Domestic.
57	N. B. Hinckley estate	do	.....	Bored, 10-inch	1,177	1,021	700+	Wind	.....	.....	.....	Domestic; irrigation.
58	Wm. Curtis	Sec. 30, T. 1 S., R. 3 W.	1885	do	1,144	1,076	76	do	150	100	.002	Domestic.
59	E. C. Curtis	Sec. 29, T. 1 S., R. 3 W.	1895	Bored, 7-inch	1,120	1,070	96	do	160	75	.002	Do.
60	R. T. Curtis	do	1895	do	1,123	1,073	86	do	140	100	.003	Do.
61	W. M. Curtis	do	1899	Bored, 12-inch	1,125	1,079	415	Cylinder pump; gas	900	1,800	.70	Irrigation.
62	N. B. Curtis	do	1895	Bored, 7-inch	1,126	1,076	84	Wind	140	60	.001	Domestic.
63	N. B. Hinckley estate	Sec. 30, T. 1 S., R. 3 W.	1899	Bored, 36-inch; Bored, 11-inch	1,150	1,103	65; 271	Centrifugal; gas	900	800	.42	Irrigation.
64	L. & M. Frink	do	1889	Bored, 7-inch	1,140	1,112	62	Wind	100	163	.....	Domestic.
65	Mrs. P. S. Stewart	do	1898	do	1,144	1,109	76	do	150	65	.001	Do.
66	Gansnor & Renwick	do	1898	do	1,140	1,110	200	do	320	90	.003	Domestic; irrigation.
67	Redlands Water Co	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,563	.....	.....	Centrifugal; electric	.....	.....	.....	Irrigation.
68	Mrs. M. Robison	Sec. 30, T. 1 S., R. 3 W.	1870	Dug, 3-foot	1,110	.....	24	Hand	.....	.....	Dry.	
69	Southern Pacific R. R. Co.	Sec. 31, T. 1 S., R. 3 W.	1890	Bored, 7-inch	1,176	1,116	75	do	145	20	.....	Domestic.
70	W. F. Whittier	do	1898	Bored, 10-inch; Bored, 7-inch	1,410	1,208	294; 212	Cylinder pump; gas	1,000	935	.14	Domestic; irrigation.
71	do	do	1898	Bored, 14-inch; Bored, 10-inch	1,150	1,108	276; 84	Force pump; gas	1,020	.....	.80	Irrigation.
72	Owen Buchanan	do	1898	Bored, 7-inch	1,265	1,149	237	Cylinder pump; gas	379	800	.14	Do.
73	W. J. Lawrence	do	1898	do	1,230	1,143	190	do	304	700	.12	Do.

122	John Dostal	Sec. 15, T. 1 S., R. 3 W.	1897	do	1,403	1,290	174	Wind	348	140	Small.	Domestic.
123	J. F. Boyd	Sec. 16, T. 1 S., R. 3 W.	1896	Bored, 10-inch (2)	1,290	1,180	100 110	Cylinder pump; gas	500	900	.20	Irrigation; domestic.
124	Wm. Lindenberg	Sec. 20, T. 1 S., R. 3 W.	1893	Bored, 7-inch	1,220	1,180	93	Wind	140	150	.009	Do.
125	H. S. Drew	Sec. 19, T. 1 S., R. 3 W.		Bored, 14-inch Bored, 10-inch	1,167	1,133	164 291	Cylinder pump; gas	1,300	1,500	.60	Do.
126	James Smith	do	1892	Bored, 7-inch	1,164	1,130	90	Hand	150	10		Domestic.
127	Bryan estate	Sec. 20, T. 1 S., R. 3 W.	1900	Bored, 10-inch Bored, 8-inch	1,190	1,143	510 118	Centrifugal; gas			.40	Irrigation.
128	A. M. Ham	Sec. 30, T. 1 S., R. 3 W.	1887	Bored, 7-inch Bored, 5-inch	1,155	1,120	150 300	Cylinder pump; gas	1,500	900		Domestic; irrigation.
129	P. H. Covington	Sec. 10, T. 2 S., R. 3 W.		Bored, 7-inch	1,440	1,392	58	Hand				
130	Clark & Brotherton	Sec. 20, T. 1 S., R. 3 W.	1900	Bored, 10-inch; bored, 8½-inch.	1,195	1,162		(a)				Domestic.
131	J. J. Prendergast	Sec. 29, T. 1 S., R. 3 W.	1893	Bored, 10-inch	1,200	1,166	422	Cylinder pump; gas	1,200	800	.30	Irrigation; domestic.
132	H. H. Cole	Sec. 30, T. 1 S., R. 3 W.	1888	Bored, 7-inch	1,140	1,108	82	Wind	140	180	Small.	Do.
133	H. S. Drew	Sec. 19, T. 1 S., R. 3 W.	1886	do	1,138		70	do	140	150	.001	Domestic.
134	C. M. Baxter	Sec. 30, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,147	1,116	100	Centrifugal; gas			.60	Irrigation.
135	do	do	1892	Bored, 7-inch	1,147	1,113	80	Hand				Domestic.
136	C. H. Lehmann	Sec. 19, T. 1 S., R. 3 W.	1891	Bored, 10-inch	1,129	1,103	458	Cylinder pump; gas	1,300	900	.40	Irrigation; domestic.
137	A. E. Cole	Sec. 30, T. 1 S., R. 3 W.	1892	Bored, 7-inch	1,125	1,104	100	Wind	160	100	.005	Do.
138	A. McCrary	do	1891	do	1,120	1,093	40	Hand	64			Domestic.
139	H. R. Scott	Sec. 19, T. 1 S., R. 3 W.		do	1,120	1,108	503	Centrifugal; gas	1,000	1,000		Irrigation; domestic.
140	do	do	1879	Bored, 6-inch	1,127	1,109	500					
141	E. H. Durnford	Sec. 24, T. 1 S., R. 4 W.	1894	Bored, 7-inch	1,103	1,093	500	Centrifugal; gas			.60	Domestic; irrigation.
142	James Birch	do	1890	do	1,096	1,087	300					Domestic.
143	do	do		do	1,098	1,081	100					
144	D. W. Roach	do	1899	do	1,102	1,087	85	Hand	130	24		Do.
145	E. F. Van Leuven	Sec. 25, T. 1 S., R. 4 W.	1890	do	1,103	1,083	48	Wind			.001	Do.
147	W. J. Doran	Sec. 30, T. 1 S., R. 3 W.	1900	Bored, 10-inch	1,106	1,086	100	do	200			Do.
148	L. R. Van Leuven	do	1882	Bored, 7-inch	1,108	1,093	270	do	600	109	.001	Domestic; irrigation.

a Unfinished.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
103	S. A. Grover	Sec. 21, T. 1 S., R. 3 W.	1890	Bored, 7-inch	1,294			Wind				Domestic; irrigation.
104	C. Cutting	do	1894	do	1,320	1,220	170	Cylinder pump; gas	$337	$340		Do.
105	Myron Sherman	Sec. 27, T. 1 S., R. 3 W.	1892	Bored, 8-inch	1,331	1,221	145	Cylinder pump; electric.	450	300		Do.
106	J. S. Hale	Sec. 21, T. 1 S., R. 3 W.	1897	Bored, 11-inch	1,272	1,202	295	Cylinder pump; gas	600	1,300	0.48	Irrigation.
107	do	do	1890	Bored, 7-inch	1,265	1,201	105	Wind	159	200	.002	Domestic; irrigation.
108	do	Sec. 17, T. 1 S., R. 3 W.	1896	Bored, 10-inch	1,220	1,164	86	do	160	75	.015	Irrigation.
109	C. A. Shaw	Sec. 21, T. 1 S., R. 3 W.	1893	Bored, 7-inch	1,267	1,217	96	do	138	87	.005	Domestic; irrigation.
110	Lewis Deck	do	1895	do	1,278	1,213	220	Cylinder pump; gas	363	678	.15	Do.
110a	do	do	1895	do	1,278	1,213	150	do			.15	Do.
111	I. E. Shaw	do	1890	do	1,247	1,197	90	Hand	150	25		Domestic.
112	Alise Van A. Lea	do	1898	Bored (2)	1,253		70 130	Cylinder pump; gas	500	700		Not used.
113	A. Gregory	do	1890	Bored, 7-inch	1,245	1,194	100	Wind				Domestic.
114	Gladysta Land and Water Co.	Sec. 20, T. 1 S., R. 3 W.	1899	Bored, 11-inch	1,240			Cylinder pump; gas				Irrigation.
115	Frank Hess	Sec. 21, T. 1 S., R. 3 W.	1897	do	1,243	1,188	163	Centrifugal; gas	326	800	.24	Domestic; irrigation.
116	C. S. Lombard	Sec. 16, T. 1 S., R. 3 W.	1897	Bored, 10-inch	1,246	1,182	180	Cylinder pump; gas			.30	Do.
117	S. Ronzone	do	1899	Bored, 9-inch	1,257	1,192	98	Wind	235	200	.014	Do.
118	Thos. Blakeley	do		Bored	1,254			Electric				Irrigation.
119	Elza Boger	do	1899	Dug, 4 by 4 foot; bored, 9-inch.	1,255	1,185	132	(a)				
120	M. R. Gay	Sec. 17, T. 1 S., R. 3 W.	1896	Bored, 11-inch (2)	1,220	1,170	105	Air compressor; electric.	200		.22	Do.
121	W. W. Story	Sec. 16, T. 1 S., R. 3 W.	1900	Bored, 10-inch	1,262	1,193	163	Cylinder pump; gas	400	1,500	.50	Domestic; irrigation.

122	John Dostal	Sec. 15, T. 1 S., R. 3 W.	1897	do	1,403	1,230	174	Wind	348	140	Small.	Domestic.
123	J. F. Boyd	Sec. 16, T. 1 S., R. 3 W.	1896	Bored, 10-inch (2).	1,290	1,180	100 110	Cylinder pump; gas	500	900	.20	Irrigation; domestic.
124	Wm. Lindenberg	Sec. 20, T. 1 S., R. 3 W.	1893	Bored, 7-inch	1,220	1,180	93	Wind	140	150	.009	Do.
125	H. S. Drew	Sec. 19, T. 1 S., R. 3 W.		Bored, 14-inch Bored, 10-inch	1,167	1,133	164 291	Cylinder pump; gas	1,300	1,300	.60	Do.
126	James Smith	do	1892	Bored, 7-inch	1,164	1,130	90	Hand	150	10		Domestic.
127	Bryan estate	Sec. 20, T. 1 S., R. 3 W.	1900	Bored, 10-inch Bored, 8-inch	1,190	1,143	510 118	Centrifugal; gas			.40	Irrigation.
128	A. M. Ham	Sec. 30, T. 1 S., R. 3 W.	1887	Bored, 7-inch Bored, 5-inch	1,155	1,120	150 300	Cylinder pump; gas	1,500	900		Domestic; irrigation.
129	P. H. Covington	Sec. 10, T. 2 S., R. 3 W.		Bored, 7-inch	1,440	1,392	58	Hand				
130	Clark & Brotherton	Sec. 20, T. 1 S., R. 3 W.	1900	Bored, 10-inch; bored, 8½-inch.	1,195	1,162		(a)				Domestic.
131	J. J. Prendergast	Sec. 29, T. 1 S., R. 3 W.	1893	Bored, 10-inch	1,200	1,166	422	Cylinder pump; gas	1,200	800	.30	Irrigation; domestic.
132	H. H. Cole	Sec. 30, T. 1 S., R. 3 W.	1888	Bored, 7-inch	1,140	1,108	82	Wind	140	180	Small.	Do.
133	H. S. Drew	Sec. 19, T. 1 S., R. 3 W.	1886	do	1,138		70	do	140	150	.001	Domestic.
134	C. M. Baxter	Sec. 30, T. 1 S., R. 3 W.	1899	Bored, 10-inch	1,147	1,116	100	Centrifugal; gas			.60	Irrigation.
135	do	do	1892	Bored, 7-inch	1,147	1,113	80	Hand				Domestic.
136	C. H. Lehmann	Sec. 19, T. 1 S., R. 3 W.	1891	Bored, 10-inch	1,129	1,103	458	Cylinder pump; gas	1,300	900	.40	Irrigation; domestic.
137	A. E. Cole	Sec. 30, T. 1 S., R. 3 W.	1892	Bored, 7-inch	1,125	1,104	100	Wind	160	100	.005	Do.
138	A. McCrary	do	1891	do	1,120	1,093	40	Hand	64			Domestic.
139	H. R. Scott	Sec. 19, T. 1 S., R. 3 W.		do	1,120	1,108	503	Centrifugal; gas	1,000	1,000		Irrigation; domestic.
140	do	do	1879	Bored, 6-inch	1,127	1,109	500					
141	E. H. Durnford	Sec. 24, T. 1 S., R. 4 W.	1894	Bored, 7-inch	1,103	1,093	500	Centrifugal; gas			.60	Domestic; irrigation.
142	James Birch	do	1890	do	1,096	1,087	300					Domestic.
143	do	do		do	1,098	1,081	100					
144	D. W. Roach	do	1899	do	1,102	1,087	85	Hand	130	24		Do.
145	E. F. Van Leuven	Sec. 25, T. 1 S., R. 4 W.	1890	do	1,103	1,083	48	Wind			.001	Do.
147	W. J. Doran	Sec. 30, T. 1 S., R. 3 W.	1900	Bored, 10-inch	1,106	1,086	100	do	200			Do.
148	L. R. Van Leuven	do	1882	Bored, 7-inch	1,108	1,093	270	do	600	109	.001	Domestic; irrigation.

a Unfinished.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
149		Sec. 30, T. 1 S., R. 3 W.		Bored, 7-inch	1,120			Wind				Domestic; irrigation.
150	O. Taylor	Sec. 32, T. 1 S., R. 3 W.	1897	do	1,210		75	do		$120	0.003	Do.
151	H. C. Hamanway	do		do	1,209			Hand				
152	G. J. Grant	do	1896	Bored, 7-inch (2)	1,206			Gas				Irrigation; domestic.
153	S. L. Gregg	do		Bored, 7-inch	1,202			Wind				Domestic.
154	H. C. Hamanway	do	1899	Bored, 10-inch	1,250	1,198	200	Cylinder pump; gas			.32	Irrigation.
155	T. Morris	do	1890	Bored, 7-inch	1,260	1,195	125	Wind			.002	Irrigation; domestic.
156	S. V. Horton	do	1891	do	1,270	1,195	125	do	$200	175	.01	Do.
157	C. T. Covington	Sec. 4, T. 2 S., R. 3 W.	1891	do	1,455	1,415	65	Hand	100	25		Domestic.
158	Mrs. Van Leuven	Sec. 25, T. 1 S., R. 4 W.	1896	do	1,105	1,085	78	do	150	15		Do.
159	J. H. Pierson	Sec. 24, T. 1 S., R. 4 W.	1884	Bored, 6-inch	1,104	1,103	605	Centrifugal; gas	10,222	1,200	.60	Domestic; irrigation.
160	F. M. Strang	Sec. 10, T. 2 S., R. 3 W.	1897	Dug, 3 by 3 foot	1,500	1,423	79	Hand	77	4		Domestic.
161	Railroad School	do	1891	Bored, 7-inch	1,527	1,427	118	do	180	25		Do.
162	D. Mulvahill	do	1891	do	1,470	1,439	61	do	115	22		Do.
163	R. P. Lauretzen	do		do	1,550	1,474	106	do				Do.
164		Sec. 4, T. 2 S., R. 3 W.		do	1,430			do				Do.
165	—— De Garmo	Sec. 8, T. 2 S., R. 3 W.		do	1,575	1,485	164	Wind				Do.
166	Smiley Brothers	Sec. 4, T. 2 S., R. 3 W.		Dug, 7 by 7 foot	1,347	1,330	23	Centrifugal; gas			.50	Irrigation.
277	L. F. Cram	Sec. 3, T. 1 S., R. 3 W.	1895	Bored, 12-inch	1,305	1,189	147	Wind	1,000	100	Small.	Domestic; irrigation.
278	C. C. Tyler	Sec. 2, T. 1 S., R. 3 W.	1900	Dug, 4 by 5 foot	1,305							
279	John McBride	Sec. 6, T. 1 S., R. 2 W.	1900	Dug, 4 by 4 foot	1,650	1,636	65	Centrifugal; gas	500	400		Irrigation; domestic.
280	do	do	1894	Hydraulic, 4 by 6 foot.	1,654	1,654	130	Tunnel, 130-foot, flows	250		.02	Irrigation.

281	Cram Brothers	Sec. 2, T. 1 S., R. 3 W	1899	Dug, 4 by 4 foot	1,600	1,485	120		300			
282	E. Highland Orange Co.	Sec. 35, T. 1 N., R. 3 W	1900	Bored, 12-inch Bored, 10-inch	1,630	1,610	280 140	Tunnel, flows	1,680		.26	Domestic; irrigation.
283	do	do	1900	Dug, 4 by 4 foot; bored, 10-inch.	1,680	1,666						
284	W. M. Bristol	Sec. 34, T. 1 N., R. 3 W	1899	Dug, 5 by 5 foot	1,650	1,634	50	Cylinder pump; gas		1,250	.30	Irrigation.
285	Highland Domestic Water Co.	Sec. 27, T. 1 N., R. 3 W	1899	Dug, 7 by 9 foot	1,440	1,411	65	2 cylinder pumps; 2 gas engines.		[a] 1,500	1.10	Domestic.
286	Highland Well Co	Sec 28, T. 1 N., R. 3 W	1899	Dug, 8 by 5 foot	1,431	1,415	46	Cylinder pump; gas			.68	Irrigation.
287	J. C. Weeks	Sec. 3, T. 1 S., R. 3 W	1900	Dug, 4 by 4 foot; bored, 12-inch.	1,295	1,181	([b])					
288	H. S. Stroven	do	1898	Bored, 10-inch	1,253	1,173	165	Cylinder pump; gas	400	1,160	.40	Irrigation; domestic.
289	N. Sutherland	Sec. 4, T. 1 S., R. 3 W	1898	Dug; bored, 12-inch.	1,227	1,160	78					Not used.
290	Pattee & Nye	Sec. 5, T. 1 S., R. 3 W	1900	Dug, 6 by 8 foot Bored, 10-inch	1,200	1,150	50 100	Rotary pump; steam			.60	Irrigation.
291	G. J. Fowler	do	1899	Dug, 5-foot	1,180	1,127	55	Hand	50	17		Domestic.
292	R. F. Cunningham	do	1890	Dug, 6-foot	1,160	1,120	43	Centrifugal; steam	150	1,450	.80	Irrigation.
293	do	do	1899	Bored, 7-inch	1,147	1,103	36	Hand	160	15		Domestic.
294	do	Sec. 31, T. 1 N., R. 3 W	1900	Dug, 5 by 5 foot Bored, 10-inch	1,260	1,226	135 90	Steam			1.04	Irrigation.
295	Redlands Water Co	Sec. 35, T. 1 S., R. 3 W	1899	do	1,568							
297	C. K. Matteson	Sec. 7, T. 1 S., R. 3 W	1884	Dug	1,103	1,080	25	Hand	30	4		Domestic.
298	do	do	1894	Bored, 10-inch	1,103	1,083	44	Centrifugal; gas	175	510	.60	Irrigation.
299	Geo. Gustave	do	1900	Dug, 4 by 6 foot	1,101	1,082	25	do	50		.30	Irrigation; domestic.
300	do	do		Dug, 3 by 4 foot	1,103	1,085	19					
301	Mrs. H. Taylor	do		Dug, 3-foot	1,102	1,080	25	Centrifugal; steam				Irrigation.
302	C. Wiltshire	Sec. 6, T. 1 S., R. 3 W	1895	Driven, 2-inch	1,102	1,080	27	Hand		25		Domestic.
303	Mrs. H. Taylor	Sec. 7, T. 1 S., R. 3 W	1891	Bored, 3-inch	1,101		235	do	300		3.00	Domestic; irrigation.
304	W. F. Somers	do	1900	Bored, 10-inch	1,101	1,081	([c])					
305	Mrs. Golden	Sec. 12, T. 1 S., R. 4 W	1900	do	1,099	1,099		Artesian				Irrigation.
306	do	do	1898	Bored, 8-inch	1,102	1,102	744	do	1,600		[d] 1.10	Domestic; irrigation.

[a] Two engines. [b] Unfinished. [c] Not completed. [d] December, 1898.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
307	W. F. Somers	Sec. 7, T. 1 S., R. 3 W	1895	Dug	1,098	1,080	20	Hand	$20		7.00	Domestic.
308	do	do	1899	Dug, 3 by 3 foot	1,097	1,079	20	do	20		4.00	Stock.
309	John Kaus	do	1899	Bored, 8-inch	1,103	1,085	20	Steam	40			Domestic.
310	F. P. Sargent	Sec. 13, T. 1 S., R. 4 W	1894	Driven, 2-inch	1,096	1,084	24	Hand	15	$10		Do.
311	S. E. Fitzhugh	Sec. 12, T. 1 S., R. 4 W	1888	Bored, 3-inch	1,080	1,073	234	do	500	6		Do.
312	do	do	1885	Bored, 7-inch	1,081	1,064	20	do	35	6		Do.
313	W. Borne	Sec. 7, T. 1 S., R. 3 W		Dug, 3½ by 3½ foot	1,103			do				Do.
314	Geo. Covalt	do	1899	Bored, 7-inch	1,104	1,079	30	do		4		Do.
315	W. F. Somers	Sec. 1, T. 1 S., R. 4 W		Bored, 3-inch	1,099	1,095	283	do				Do.
316	W. K. Bledsoe	do		Dug, 4½-foot	1,103	1,086	21	do	25	3		Do.
317	T. J. West	do	1900	Dug, 5-foot	1,093	1,090	20	Centrifugal; steam	400	820	1.30	Irrigation.
318	S. Van Leuven	Sec. 6, T. 1 S., R. 3 W	1883	Bored, 3-inch	1,104	1,105	309	Wind				Irrigation; domestic.
319	Ed. Dailey	do	1890	do	1,102	1,091	325	Hand				Domestic.
320	do	do	1890	do	1,106	1,105	320					Not used.
321	do	do	1885	do	1,103	1,093	350	Hand				Domestic.
322	W. A. Brouse	do	1899	Dug	1,104	1,084	22	do	25	5		Do.
323	do	do	1884	Dug, 5-foot	1,104	1,084	26	Centrifugal; steam	150	630	.50	Irrigation.
324	do	do	1893	do	1,106	1,086	25	do	150	620	.50	Do.
325	Herman Smith	do	1899	Dug, 4 by 4 foot	1,109	1,084	27	Hand	100	12		Domestic.
326	J. Friedmann	do	1885	Dug, 6-foot	1,107	1,090	22	Centrifugal; steam	130	485	1.00	Irrigation; domestic.
327	J. Dunlap	Sec. 1, T. 1 S., R. 4 W		Bored, 3-inch	1,102	1,102	185	Artesian			.18	Domestic.
328	H. C. Keller	do	1880	Bored, 2-inch	1,104	1,104	169	do			.02	Do.
329	A. Roberts	Sec. 6, T. 1 S., R. 3 W	1892	Bored, 3-inch	1,105	1,105	231	do	426		.005	Do.
330	Warm Creek School	do	1885	Bored, 2-inch	1,106	1,101	150	Hand	175			Do.
331	W. L. McKenzie	Sec. 1, T. 1 S., R. 4 W	1875	do	1,105	1,105	320	Artesian			.01	Irrigation; domestic.

332	Wm. Shay	Sec. 31, T. 1 N., R. 3 W.	1890	Bored, 3-inch	1,103	1,103	150	do	800		.06	Domestic.
333	Wm. Clyde	Sec. 6, T. 1 S., R. 3 W.	1889	Bored, 2-inch	1,106	1,106	146	do	150		.03	Irrigation; domestic.
334	Riverside Water Co.	Sec. 1, T. 1 S., R. 4 W.	1898	Bored, 10-inch	1,086		648	do				Irrigation.
335	do	do	1898	do	1,088		590	do	1,100		1.20	Do.
336	do	do	1898	Bored	1,085		334	do				Do.
337	do	do		do	1,084	1,084	440	do				Do.
338	Redlands Domestic Water Co.	Sec. 35, T. 1 S., R. 3 W.	1899	Bored, 10-inch (2)	1,640	1,550	243 400	Centrifugal; electric	650		.80	Domestic.
339	Thos. Shay	Sec. 31, T. 1 N., R. 3 W.	1888	Bored, 7-inch	1,103	1,089	20	Hand	30	5		Do.
340	do	do	1895	Dug, 4 by 4 foot Bored, 8-inch	1,098		80	Cylinder pump; gas	300	1,680	.50	Irrigation.
341	R. T. Clyde	Sec. 6, T. 1 S., R. 3 W.	1880	Bored, 2-inch	1,105	1,105	133	Artesian	100			Domestic; irrigation.
342	F. L. Talmadge	do	1880	do	1,106	1,106	135	Hand	100	5		Domestic.
343	Talmadge & Haws	do	1897	Bored, 10-inch	1,140	1,132	425	Centrifugal; gas	850	986	2.00	Irrigation.
344	Mrs. Haws	do	1898	Bored, 2-inch	1,125	1,125	100	Hand	75	3		Domestic.
345	John D. Clark	Sec. 31, T. 1 N., R. 3 W.	1899	Bored, 3-inch	1,130	1,130	125	Artesian	120		.02	Domestic; irrigation.
346	do	do	1892	do	1,132	1,132	50	do	45			Do.
347	D. R. Seely	Sec. 33, T. 1 N., R. 3 W.	1890	do	1,250	1,176	124	Wind			.005	Domestic.
348	do	do	1899	Bored, 12-inch	1,285	1,110	195	Cylinder pump; gas				Irrigation.
349	W. D. Stevens	Sec. 5, T. 1 S., R. 3 W.	1894	Dug, 8-foot Bored, 10-inch	1,180	1,130	40 60	Centrifugal; gas		815	.60	Irrigation; domestic.
350	Jane C. Goodman	Sec. 6, T. 1 S., R. 3 W.	1894	Bored, 3-inch	1,140	1,128	284	Wind	625	108	.001	Do.
351	Jas. Roddick	Sec. 5, T. 1 S., R. 3 W.	1898	Dug, 4-foot	1,143	1,114	30	Centrifugal; gas		250	.20	Do.
352	Saml. Roddick	Sec. 6, T. 1 S., R. 3 W.	1899	Driven, 1¼-inch	1,139	1,117	27	Hand	7	10		Domestic.
353	W. F. Talmadge	do	1885	Bored, 7-inch	1,148	1,132	30	Wind		80	.001	Domestic; irrigation.
354	do	do	1891	Bored, 3-inch	1,146	1,131	41	Hand		6		Domestic.
355	A. Downey	do	1899	Driven, 1¼-inch	1,143	1,131	21	do	4	3		Do.
356	F. A. Haws	do	1899	Driven, 1¼-inch	1,130	1,120	26	do	5	5		Do.
357	E. S. Haws	do	1899	do	1,130	1,120	20	do	5	5		Do.
358	Mrs. M. C. Haws	do	1895	Bored, 3-inch	1,125	1,125	125	Artesian	250			Do.
359	Walter Shay	Sec. 31, T. 1 N., R. 3 W.		Bored, 7-inch	1,110			Hand				Do.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
360	Kohl Bros.	Sec. 32, T. 1 N., R. 3 W.	1890	Bored, 6-inch	1,147	1,129	60	Wind			.001	Domestic.
361	H. D. Rabel	Sec. 31, T. 1 N., R. 3 W.	1896	Bored, 2-inch	1,140	1,140	68	Artesian	$40			Do.
362	do	do	1898	Bored, 3-inch	1,142	1,142	86	do	70		.01	Do.
363	do	do	1898	do	1,139	1,139	44	do	30		.25	Do.
364	do	do		do	1,137	1,137	72	do	70		.005	Do.
366	D. J. Carpenter	Sec. 24, T. 1 N., R. 4 W.	1900	Dug, 6 by 9 foot	1,470	1,447	25					
367					1,475	1,475	71				.06	
368					1,474	1,474	123				.10	
369					1,474	1,474	193				.08	
370	D. J. Carpenter & Co.	do		Bored, 7-inch	1,476	1,476	184	Centrifugal; gas		$1,100	.14	Irrigation.
371					1,473	1,473					.10	
372					1,473	1,473	127				.10	
373					1,473	1,473	167				.06	
374	W. J. Lindville	Sec. 30, T. 1 N., R. 3 W.	1899	Bored, 10-inch	1,270	1,140	368	Cylinder pump; gas		3,000	.36	Do.
375	Mrs. R. L. Burcham	Sec. 31, T. 1 N., R. 3 W.	1899	Bored, 12-inch	1,224	1,154	460	do	1,200	2,250	.70	Do.
376	E. K. Henderson	Sec. 30, T. 1 N., R. 3 W.	1899	Bored, 3-inch	1,233	1,133	134	Wind	150			Domestic.
377	Jas. McCafferty	Sec. 31, T. 1 N., R. 3 W.	1896	Bored, 7-inch	1,225		80-100	Cylinder pump; gas		2,500	.40	Irrigation; domestic.
378	J. D. Clark	do	1897	Bored, 11-inch	1,170		106	do			.40	Irrigation.
379	P. W. Gray	do	1893	Bored, 7-inch	1,170	1,120	139	Wind			.03	Domestic; irrigation.
381	John Lin Foster	Sec. 32, T. 1 N., R. 3 W.	1894	Bored, 10-inch	1,220		95	do	600	(a)	.003	Do.
382	P. H. Gleason	do	1900	Dug, 4 by 4 foot	1,250	1,175	78	do			.002	Do.
383	E. L. Cumbl	do	1897	do	1,128	1,091	88	Hand	50			Domestic.
384	A. C. Pierce	do	1898	do	1,210	1,150	62	Wind	120	140	.005	Domestic.
385	Kohl Bros.	do	1898	Bored, 10-inch	1,148	1,136	300	Centrifugal; gas				

386	State of California Hospital for Insane.	Sec. 5, T. 1 S., R. 3 W.	.....	....do	1,110	1,078	85	Centrifugal; electricity	.....	.....	1.00	Irrigation.
387	Geo. Fowler	Sec. 32, T. 1 N., R. 3 W.	1888	Dug, 3 by 3 foot	1,165	1,137	29	Hand	.....	.....	.....	Domestic.
388	C. D. Fowler	Sec. 5, T. 1 S., R. 3 W.	1895	Dug, 4 foot	1,168	1,135	34	....do	.....	.....	.....	Do.
389	J. Bagwell	Sec. 32, T. 1 N., R. 3 W.	1900	Dug, 4 by 4 foot; bored, 12-inch.	1,230	1,117	153	Cylinder pump; gas	.....	.....	.20	Irrigation.
390	A. A. Boyd	....do	1895	Dug; bored, 7-inch	1,290	1,138	202	....do	.....	.....	.22	Irrigation; domestic.
391	Gage Canal Co	Sec. 13, T. 1 S., R. 4 W.	1891	Bored, 10-inch	1,058	1,058	168	Artesian	.....	.....	[b] 4.306	Irrigation.
392	....do	....do	1891	....do	1,059	1,059	166	....do	.....	.....	[b] 1.521	Do.
394	....do	....do	1891	....do	1,063	1,063	123	....do	.....	.....	[b] 1.712	Do.
395	....do	....do	1891	....do	1,066	1,066	125	....do	.....	.....	[b] .594	Do.
396	....do	Sec 18, T. 1 S., R. 3 W.	1887	....do	1,062	1,062	144	....do	.....	.....	[b] 2.131	Do.
397	....do	....do	1887	Bored, 10½-inch	1,064	1,064	140	....do	.....	.....	[b] 1.011	Do.
398	....do	....do	1888	Bored, 10-inch	1,075	1,075	138	....do	.....	.....	[b] .605	Do.
399	....do	....do	1888	....do	1,075	1,075	106	....do	.....	.....	[b] .188	Do.
400	....do	....do	1888	....do	1,074	1,074	130	....do	.....	.....	[b] .563	Do.
401	....do	....do	1888	....do	1,071	1,071	146	....do	.....	.....	[b] 2.212	Do.
402	....do	....do	1888	....do	1,065	1,065	116	....do	.....	.....	[b] 3.176	Do.
403	....do	....do	1888	....do	1,064	1,064	134	....do	.....	.....	[b] 1.424	Do.
404	....do	....do	1888	....do	1,061	1,061	116	....do	.....	.....	[b] .594	Do.
405	....do	Sec. 13, T. 1 S., R. 4 W.	1887	....do	1,057	1,057	147	....do	.....	.....	[b] 2.254	Do.
406	....do	....do	1887	....do	1,058	1,058	122	....do	.....	.....	[b] 1.026	Do.
407	....do	....do	1892	....do	1,059	1,059	115	....do	.....	.....	[b] .484	Do.
408	....do	....do	1892	Bored, 10½-inch	1,053	1,053	169	....do	.....	.....	[c] 8.105	Do.
409	....do	Sec 18, T. 1 S., R. 3 W.	1886	Bored, 7-inch	1,077	.....	127	([d])	.....	.....	[c] .286	Do.
410	....do	....do	1886	....do	1,076	.....	127	([d])	.....	.....	[c] .302	Do.
411	....do	....do	1886	....do	1,077	.....	125	([d])	.....	.....	[c] .270	Do.
412	....do	....do	1886	....do	1,077	.....	125	([d])	.....	.....	[c] .416	Do.

[a] Included in cost of well.
[b] Flow of wells Nos. 391 to 412 is given for October, 1892.
[c] December, 1898.
[d] Wells 409 to 412 are pumped by 15-horsepower gas engine and centrifugal pump, raising 2 second-feet of water. These were artesian wells when sunk.

Wells in San Bernardino quadrangle.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
1	Riverside Water Co	Sec. 27, T. 1 S., R. 4 W	1887	11-inch pipe	1,014	1,014	115	Artesian			[a] 0.329	Domestic.
2	do	do		do	1,015	1,015	118	do			[b] .284	Do.
3	do	do		do	1,015	1,015	113	do			[b] .117	Do.
4	do	do		do	1,016	1,016	111	do			[b] .153	Do.
5	do	do		do	1,014	1,014	112	do			[b] .117	Do.
6	do	do		do	1,016	1,016	120	do			[b] .150	Do.
7	do	do	1888	7-inch pipe	1,013	1,013	128	do	$400		[b] .150	Do.
8	do	do	1888	9-inch pipe	1,016	1,016	125	do	525		[b] .096	Do.
9	do	do	1888	9.5-inch pipe	1,018	1,018	123	do	500			Do.
10	do	do	1888	9-inch pipe	1,017	1,017	127	do	550			Do.
11	do	do	1888	do	1,021	1,021	201	do	800		[b] .125	Do.
12	do	do		do	1,020	1,020	141	do	650			Do.
13	do	do	1889	do	1,015	1,015	127	do	525			Do.
14	do	do	1889	do	1,014	1,014	125	do	550		[b] .068	Do.
15	do	Sec. 22, T. 1 S., R. 4 W	1889	11-inch pipe	964	964	86	do	480		[c] .442	Irrigation.
16	do	do	1889	9-inch pipe	981	981	123	do			[c] .083	Do.
17	do	do	1889	do	955	955	81	do			[c] .900	Do.
18	do	do	1889	do	955	955	92	do			[c] .361	Do.
19	do	Sec. 16, T. 1 S., R. 4 W	1889	do	972	972	225	do			[b] .158	Do.
[d] 20	do	do	1889	7-inch pipe	978	978	75					
[d] 21	do	do	1891	do	971	971	175					
22	do	do	1889	9-inch pipe	973	973	55	Artesian			.173	Do.
23	do	do	1889	do	974	974	121	do			.355	Do.
24	do	Sec. 22, T. 1 S., R. 4 W	1889	7-inch pipe	989	989	192	do			[c] .176	Do.
25	do	do	1889	9-inch pipe	968	968	81	do			[c] .207	Do.
26	do	do	1889	do	967	967	83	do			[c] .361	Do.

27	.....do.....	.....do.....	1889	.....do.....	981	981	103	.....do.....			[e].952	Do.
28	.....do.....	.....do.....	1889	.....do.....	970	970	83	.....do.....			[e].273	Do.
29	.....do.....	.....do.....	1889	.....do.....	979	979	101	.....do.....			[e].640	Do.
30	.....do.....	.....do.....	1890	.....do.....	978	978	97	.....do.....			[e]1.417	Do.
31	.....do.....	.....do.....	1890	.....do.....	980	980	165	.....do.....			[e].569	Do.
32	.....do.....	.....do.....	1890	.....do.....	979	979	165	.....do.....			[e].616	Do.
33	.....do.....	Sec. 27, T. 1 S., R. 4 W..	1891	9.5-inch pipe.....	1,012	1,012	330	.....do.....			[b]3.28	Domestic.
34	.....do.....	.....do.....	1891	.....do.....	1,012	1,012	326	.....do.....			.....	Do.
35	.....do.....	Sec. 22, T. 1 S., R. 4 W..	.....	.....do.....	977	977	82	.....do.....	255	.....	[f].860	Irrigation.
37	.....do.....	Sec. 27, T. 1 S., R. 4 W..	.....	.....do.....	1,012	1,012	249	.....do.....			.....	Domestic.
38	.....do.....	Sec. 1, T. 1 S., R. 4 W...	1892	7-inch pipe.....	1,083	1,083	187	.....do.....	662	.....	[g].027	Irrigation.
39	.....do.....	.....do.....	1893	9.5-inch pipe.....	1,083	1,083	396	.....do.....			[g].714	Do.
42	.....do.....	Sec. 27, T. 1 S., R. 4 W..	1893	.....do.....	1,011	1,011	344	.....do.....			.....	Domestic.
43	.....do.....	Sec. 1, T. 1 S., R. 4 W...	1894	.....do.....	1,086	1,086	420	.....do.....	630	.....	[h]1.452	Irrigation.
44	.....do.....	Sec. 22, T. 1 S., R. 4 W..	1896	9-inch pipe.....	979	979	133	.....do.....	250	.....	[e].971	Do.
45	.....do.....	.....do.....	1896	.....do.....	979	979	173	.....do.....	420	.....	.....	Do.
47	.....do.....	Sec. 3, T. 1 S., R. 4 W...	1898	.....do.....	1,025	1,025	168	.....do.....	500	.....	.....	Do.
51	.....do.....	Sec. 22, T. 1 S., R. 4 W..	.....	8-inch pipe.....	954	954	78	.....do.....			.....	Do.
52	.....do.....	.....do.....	.....	.....do.....	955	955	94	.....do.....			.....	Do.
53	.....do.....	.....do.....	1898	.....do.....	956	956	68	.....do.....			.....	Do.
54	.....do.....	.....do.....	1898	.....do.....	957	957	68	.....do.....			.....	Do.
55	.....do.....	.....do.....	1898	7-inch pipe.....	958	958	92	.....do.....			.....	Do.
56	.....do.....	.....do.....	1898	.....do.....	959	959	75	.....do.....			.....	Do.
57	.....do.....	.....do.....	1898	8-inch pipe.....	960	960	92	.....do.....	128		.....	Do.
58	.....do.....	.....do.....	1898	7-inch pipe.....	960	960	87	.....do.....	157	.....	[i].456	Do.
59	.....do.....	.....do.....	1898	8-inch pipe.....	961	961	85	.....do.....	138	.....	[i].622	Do.
60	.....do.....	.....do.....	1898	7-inch pipe.....	961	961	93	.....do.....	173	.....	[i].456	Do.
61	.....do.....	.....do.....	.....	8-inch pipe.....	952	952	.....	.....do.....			.....	Do.
62	.....do.....	Sec. 15, T. 1 S., R. 4 W..	1898	.....do.....	985	985	183	.....do.....			[i].34	Do.
65	.....do.....	Sec. 2, T. 1 S., R. 4 W...	1900	10-inch pipe.....	1,040	1,040	540	.....do.....			2.89	Do.
66	.....do.....	.....do.....	1900	.....do.....	1,035	1,035	580	.....do.....			2.606	Do.
67	Wm. Roach.....	Sec. 6, T. 2 S., R. 4 W...	1889	7-inch pipe.....	904	852	130	10 wind.....	200	$160	.015	Irrigation; domestic.

[a] 1890. [b] 1891. [c] 1896. [d] Well filled and covered with sand from flood and lost. [e] 1896. [f] 1892. [g] 1900. [h] 1894. [i] 1898.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
68	Wm. Roach	Sec. 6, T. 2 S., R. 4 W.	1875	7-inch pipe	905	852	70	12 wind	$105	$130	.006	Irrigation.
69	Mrs. Douglas	do	1893	do	895	835	112	Wind			.015	Irrigation; domestic.
70	Louise Peña	Sec. 12, T. 2 S., R. 5 W.	1888	Dug, 3 by 4 foot	835	815	22	do		110	Small.	Domestic.
71	P. Evans	do	1900	10-inch pipe	840	840	400	Artesian			1.000	Irrigation.
72	P. Baca	do	1899	Dug, 3 by 3 foot	852	832	22	Hand	20		Small.	Domestic.
73	W. L. Zader	Sec. 29, T. 1 S., R. 4 W.	1894	Dug, 3-foot diameter.	980	930	52	8 wind	40	35	Small.	Do.
74	D. Jones	do	1888	do	980		70	Wind	100	200		
75	T. J. Smith	Sec. 30, T. 1 S., R. 4 W.	1890	do	974		38	do				
76	Mrs. B. R. Atkins	do	1897	do	980	938	59	9 wind		500	Small.	Do.
77		do		Dug, 3 by 3 foot	886	871	17	Hand				Do.
78	M. G. Soares	do		do	875	871	6	do				Do.
79	Thos. McGraw	Sec. 35, T. 1 S., R. 5 W.	1895	Dug, 4 by 4 foot	875	837	39	do	70	14	Small.	Do.
80	Henry Carson	Sec. 10, T. 2 S., R. 5 W.	1900	Dug, 3-foot diameter.	831	784	49		40	40		Do.
81	Dan Baker	do	1885	6-inch pipe	826	786	60	Hand		20		Do.
82	Mrs. Burgess	Sec. 34, T. 1 S., R. 5 W.		Dug, 4 by 4 foot	988	848	150	Wind				Not used.
83	T. Pulley	Sec. 10, T. 2 S., R. 5 W.	(a)	Bored, 20-inch	881	808	89					
84	Mrs. L. M. Henry	do	1898	6-inch pipe	895	787	128	Wind				Irrigation; domestic.
85	T. Pulley	do	1896	Dug, 3-foot diameter.	850	780	72	do	50	120		Do.
86	John Miller	do	1900	do	866	800	69	do	40			Domestic.
87	Ed. Bridson	Sec. 15, T. 2 S., R. 5 W.	1898	7-inch pipe	840	780	100	10 wind	150	150		Domestic; stock.
88	J. Rogerson	do		Dug, 4 by 4 foot	830	794	37	Hand				Domestic.
89	Mrs. A. Parks	do		7-inch pipe	810	793	28	Wind				Domestic; stock.

90	H. C. Parks	Sec. 9, T. 2 S., R. 5 W.	1887	Dug, 3-foot diameter.	850	784	75	do	325	180		Do.
91	Scott La Rue	do	1900	do	845	742	107	do	100	285		Do.
92	Emuel Spooner	Sec. 8, T. 2 S., R. 5 W.	1896	Dug, 4 by 4 foot	850	750	105	do	115			Do.
93	do	do	1900	do	850	750	107		125			
94	W. J. Thomas	Sec. 7, T. 2 S., R. 5 W.	1900	Dug, 4½ by 4 foot	847	817	35		70			Domestic.
95	E. Thomas	do	1899	Dug, 3 by 3 foot	850	814	41	Wind	75	150		Irrigation.
96	do	do	1894	do	841	817	26	Hand	40			Domestic.
97	Mrs. H. M. Thurber	Sec. 12, T. 2 S., R. 6 W.	1896	Dug, 5-foot diameter.	800	782	28	Wind				Irrigation; domestic.
98	F. D. Lewis	Sec. 13, T. 2 S., R. 6 W.		Dug, 4 by 4 foot	795	775	40	10 wind				Domestic.
99		Sec. 12, T. 2 S., R. 6 W.		do	789	770	31	do				Do.
100	John Parkhurst	do	1898	Dug, 6-foot diameter.	818	807	13.5	12 wind	100	135		Do.
101	J. R. Johnston	Sec. 6, T. 2 S., R. 5 W.		Pipe line								Domestic; stock.
102	I. McBride	Sec. 12, T. 2 S., R. 6 W.	1892	Dug, 3.5 by 3.5 foot	813	787	55	8 wind	80	100	Small.	Domestic.
103	Milo Gilbert	Sec. 24, T. 1 S., R. 4 W.	1900	7-inch pipe	1,004	864	220	12 wind				
104	Riverside Trust Co.	do	1898	10-inch pipe	1,077	1,077	506	Artesian			1.600	Irrigation.
105	do	do	1898	do	1,071	1,071	531	do			1.200	Do.
106	do	do	1898	do	1,065	1,065	517	do			1.400	Do.
107	do	Sec. 23, T. 1 S., R. 4 W.	1899	do	1,045	1,045	675	do			1.500	Do.
108	do	Sec. 24, T. 1 S., R. 4 W.	1899	do	1,076	1,076	568	do			2.040	Do.
109	do	Sec. 26, T. 1 S., R. 4 W.	1899	do	1,019	1,019	554	do			.400	Do.
110	do	Sec. 13, T. 1 S., R. 4 W.	1899	do	1,052	1,052	580	do				Do.
111	do	do	1899	do	1,061	1,061	537	do			2.600	Do.
112	do	do	1899	do	1,066	1,066	577	do			1.200	Do.
113	do	do	1899	do	1,069	1,069	505	do			1.040	Do.
114	do	do	1900	do	1,079	1,079	478	do			3.000	Do.
115	Gage Canal Co	Sec. 26, T. 1 S., R. 4 W.	1891	do	1,033	1,033	656	do			.089	Do.
116	do	do	1891	do	1,034	1,034	534	do			.956	Do.
117	do	do	1891	do	1,034	1,034	582	do			.770	Do.
118	do	do	1891	do	1,034	1,034	482	do			1.026	Do.
119	do	do	1891	10½-inch pipe	1,034	1,034	320	do			.064	Do.
120	do	do	1891	10-inch pipe	1,034	1,034	784	do			1.089	Do.

a Not finished.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
121	Gage Canal Co	Sec. 23, T. 1 S., R. 4 W.	1888	10½-inch pipe	1,036	1,036	196	Artesian			.550	Irrigation.
122	do	do	1888	do	1,036	1,036	190	do			.979	Do.
123	do	do	1889	10-inch pipe	1,036	1,036	142	do			.188	Do.
124	do	do	1889	10½-inch pipe	1,036	1,036	148	do			.121	Do.
125	do	Sec. 24, T. 1 S., R. 4 W.	1886	7-inch pipe	1,037	1,037	141	do			2.330	Do.
126	do	Sec. 13, T. 1 S., R. 4 W.	1886	do	1,037	1,037	181	do			1.928	Do.
127	do	do	1891	10-inch pipe	1,037	1,037	426	do			5.901	Do.
128	do	do	1891	do	1,037	1,037	472	do			1.874	Do.
129	do	do	1891	do	1,048	1,048	518	do			1.874	Do.
130	do	do	1891	do	1,049	1,049	338	do			1.264	Do.
131	do	do	1891	do	1,049	1,049	380	do			.770	Do.
132	do	do	1891	do	1,049	1,049	386	do			1.424	Do.
133	do	do	1891	do	1,052	1,052	198	do			5.314	Do.
134	do	do	1891	do	1,057	1,057	124	do			1.299	Do.
135	do	do	1891	do	1,055	1,055	116	do			2.746	Do.
136	do	do	1891	do	1,057	1,057	131	do			5.663	Do.
155	do	do	1892	do	1,051	1,051	193	do			8.239	Do.
156	do	do	1892	do	1,046	1,046	192	do			8.315	Do.
157	do	do	1892	10½-inch pipe	1,044	1,044	390	do			4.835	Do.
158	do	do	1892	10-inch pipe	1,042	1,042	224	do			5.697	Do.
159	do	do	1885	7-inch pipe	1,045		123				1.923	Do.
160	do	do	1885	do	1,045		133				.473	Do.
161	do	do	1885	do	1,045		133				3.015	Do.
162	do	do	1885	5-inch pipe	1,048		139				8.217	Do.
163	do	do	1885	7-inch pipe	1,048		211				4.641	Do.
164	do	do	1885	do	1,046		100				.579	Do.

170	Riverside Trust Co	Sec. 22, T. 1 S., R. 5 W.	1900	12-inch pipe	1,100	858	454	....do			6.131		Do.
171	Bloomington Land Co	Sec. 8, T. 1 S., R. 4 W.		8-inch pipe	1,095	1,081	283		$1,200				Not used.
172	D. Johnson				1,089				600				Do.
173	Fox, Archibald & Lantz	do						Centrifugal; 10 gas			.414		Irrigation.
174	Jas. Lamb	do	1894	8-inch pipe	1,097	1,083	102	do	200	$1,800	.400		Do.
175	Jas. Barnhill	do		do	1,097			Centrifugal; 15 electric			.800		Do.
176	City of Colton	do	1899	10-inch pipe	1,087	1,070	490	Centrifugal; electric			.834		Irrigation; domestic.
177	do	do	1899	8-inch pipe	1,084	1,068	90	do			.200		Do.
178	G. W. Curtis	Sec. 24, T. 1 S., R. 4 W.	1895	7-inch pipe	1,088	1,063	85	8 wind	130	70	.002		Do.
179	J. J. Curtis	do	1892	do	1,088	1,063	90	do	150	120	.003		Do.
180	A. C. Harvey	do	1898	do	1,088	1,088	600	Centrifugal; 12 gas	400	1,200	2.250		Irrigation.
181	W. A. Thomas	do			1,078	1,076		Artesian					
182	L. S. Dart	Sec. 25, T. 1 S., R. 4 W.	1890	7-inch pipe	1,075	1,055	80	12 wind	150		.002		Domestic.
183	Anderson estate	do		8-inch pipe 4.5-inch pipe	1,093		450 150	Centrifugal; 25 gas		2,275	.250		Irrigation.
184	A. Hunt	Sec. 27, T. 1 S., R. 4 W.	1889	7-inch pipe	1,005	1,005	127	Artesian	200		.100		Irrigation; domestic.
185	do	do	1889	do	1,001	1,001	57	do	90		.800		Irrigation.
186	do	do	1895	9¼-inch pipe	1,004	1,004	280	do	1,100		.400		Do.
187	do	do	1894	7-inch pipe	1,007	1,007	200	do	500				Do.
188	No record.												
189	E. M. Cooley	do	1889	do	1,019	959	86	12 wind	150	100			Irrigation; domestic.
190	H. L. Drew	Sec. 21, T. 1 S., R. 4 W.		3-inch pipe	980	980	200	Artesian			.010		Domestic.
191	C. C. Cooley	Sec. 27, T. 1 S., R. 4 W.	1885	7-inch pipe	993	928	85	12 wind	150	100			Do.
192	P. Filance	do	1887	10-inch pipe	983	983	250	Artesian	1,000		1.200		Irrigation.
193	Filance estate	do	1880	3-inch pipe (3)	984	984	75 85 90	do			.900		Irrigation; domestic.
194	O. A. Byrne	Sec. 21, T. 1 S., R. 4 W.		2-inch pipe	984	980		Hand		5			Domestic.
195	Harry Whaley	Sec. 34, T. 1 S., R. 4 W.	1890	7-inch pipe	1,150	1,115	100	8 wind			.001		Do.
196	Thomas N. Hunt	do	1890	Dug, 3-foot diameter.	1,117	1,000	123	16 wind	750	100			Do.
197	Mr. Blair	do	1899	Dug, 5 by 5 foot	1,115	1,109	16	Never used					

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
198	Ignacio Reyes	Sec. 34, T. 1 S., R. 4 W.	1895	Dug	1,182	1,172	13		$15	$3		Domestic.
199	Washington School	Sec. 27, T. 1 S., R. 4 W.		7-inch pipe	1,043	966	129	8 wind		90		Do.
200	S. A. Pooles	Sec. 33, T. 1 S., R. 4 W.	1890	do	1,015	955	75	12 wind		500	.005	
201	Fred Pooles	do	1901	8¼-inch pipe	955	907	98	8 wind				Do.
202	Mrs. C. A. Peake	do	1880	2-inch pipe	950	936	18	Hand	10			Do.
203	Chas. Green	do		3-inch pipe	944		3	Wind				Do.
204	J. D. Warner	Sec. 28, T. 1 S., R. 4 W.	1884	1¼-inch pipe	938	927	13	Hand	10			Do.
205	do	do	1898	1¼-inch pipe	926	916	13	do	8			Do.
206	do	do	1894	10-inch pipe	941	935	155		2,455			
207	Geo. Cooley, sr.	Sec. 27, T. 1 S., R. 4 W.	1894	7-inch pipe	978	952	72	12 wind		125	.005	Irrigation; domestic.
208	C. A. Poole	do	1900	do	1,002	984	50	Hand	110			Domestic.
209	A. A. Warren	Sec. 33, T. 1 S., R. 4 W.	1885	2-inch pipe	936	929	25	12 wind	15	150	.002	Irrigation; domestic.
210	West Riverside Water Co.	Sec. 32, T. 1 S., R. 4 W.			950	944	112	30 compressor		1,275		Irrigation.
211	J. M. Snodgrass	Sec. 28, T. 1 S., R. 4 W.	1898	Dug, 10-foot diameter.	931	927	13	Bucket pump; engine	50	600	.500	Do.
212	do	do	1898	Dug, 2-foot diameter.	923	920	7.5	12 wind	10	50	.003	Do.
213	A. A. Warren	Sec. 33, T. 1 S., R. 4 W.	1897	2-inch pipe	943	936	15	Hand	15	5		Domestic
214	Southern Pacific R. R. Co.	Sec. 21, T. 1 S., R. 4 W.	1882	7-inch pipe	958	915	45	12 wind			.005	Do.
215	Frank Parody	Sec. 28, T. 1 S., R. 4 W.	1900	Dug	955	934	33	Hand		12		Do.
216	Martin Gahm	Sec. 21, T. 1 S., R. 4 W.	1888	Dug, 3 by 3 foot	964	927	41	8 wind	50	75	.005	Do.
217	W. H. Wells	do	1893	Dug, 2.5 by 2.5 foot.	966	928	44	Hand	6			Do.
218	C. G. Turner	do	1895	7-inch pipe	966		70	12 wind				
219	G. B. Kinyon	do	1888	Dug, 3 by 3 foot	948	934	25	Wind	25	500		Irrigation; domestic.
220	J. F. Stuchberry	do	1886	Dug, 3.5 by 3.5 foot.	952	933	22	8 wind	30	90	.007	Do.

221	J. H. Vaughan	do	1886	Dug, 4-foot diameter.	959	928	34	do	62	155		Irrigation.
222	Alfred Vaughan	do	1900	do	965			do			.009	Irrigation; domestic.
223	W. L. Vaughan	do	1884	do	963	931	40	Hand	40			Domestic.
224	H. D. Young	do	1890	Dug, 2-foot diameter.	969	926	50	8 wind		105	.003	Irrigation; domestic.
225	J. H. Dodson	do	1885	Dug, 4-foot diameter.	964	922	43	12 wind	84		.006	Do.
226	Henry Kaiser	do	1892	do	968	928	55	8 wind		212		Do.
227	H. C. Dodson	do	1892	Dug, 2-foot diameter.	970	916	62	12 wind			.002	Do.
228	John Benner	do	1880	Dug, 4-foot diameter.	974	921	54	Hand			Small.	Domestic.
229	Tom Moran	do		do	978	924	68	14 wind		155	.001	Do.
230	T. Allen	do	1880	do	984	928	69	12 wind			.009	Irrigation; domestic.
231	S. A. Woodard	do	1882	Dug, 4.5-foot diameter.	1,000	Dry.	70	10 wind				
232	Los Angeles Building Co.	do		Dug, 4 by 4 foot	1,000	934	80	12 wind			.005	Do.
233	J. A. Coburn	Sec. 16, T. 1 S., R. 4 W.	1890	do	1,038	1,038	3	8 wind	5	65	.002	Do.
234	Miss B. Top	do			1,019	991	28	Centrifugal; 3 electric	300	376	.6	Do.
235	Byron Waters	do	1893	Dug, 9.5 by 9.5 foot and 5 by 5 foot.								
235a	do	do	1889	3-inch pipe	1,019		220	Artesian	700		.005	Do.
236	Doctor Rowl			Pipe				do				
237	do			do				do				
238	Homer Jones	Sec. 16, T. 1 S., R. 4 W.	1895	3-inch pipe	1,023	1,010	300	8 wind			.002	Do.
239	Mrs. M. G. Hammel	do			1,008	1,000	83	do		75	.002	Do.
240	Riverside Trust Co.	Sec. 23, T. 1 S., R. 4 W.		7-inch pipe	1,000			Hand				Domestic.
241	F. S. West	do	1897	2-inch pipe	998							Irrigation; domestic.
242	Mrs. E. A. Paine	Sec. 22, T. 1 S., R. 4 W.	1896	3-inch pipe	1,000	1,000	109	Artesian		75	.04	Do.
243	M. B. Warren	do	1885	4-inch pipe	996	996	125	do			.01	Do.
243a	do	50 feet southeast from 243.	1899	3-inch pipe	997	997	130	do			.25	Irrigation.
244	do	Sec. 22, T. 1 S., R. 4 W.	1880	2-inch pipe	998	998	125	do			.041	Irrigation; domestic.

Wells in San Bernardino quadrangle—Continued.

No. of well	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
244*a*	M. B. Warren	20 feet southwest from 244.	1899	3-inch pipe	997	997		Artesian			.178	Irrigation; domestic.
245	C. E. Bishop	Sec. 23, T. 1 S., R. 4 W.	1882	do	1,001	1,001	94	do	$125		.02	Do.
245*a*	do	do	1888	7-inch pipe	1,004	1,004	94	do			.02	Do.
246	Wm. E. Everett	Sec. 22, T. 1 S., R. 4 W.	1898	3-inch pipe	1,001	1,001	96	do	100		.25	Do.
247	Bob Gomer	Sec. 15, T. 1 S., R. 4 W.	1890	do	984							
248	John Welsh	Sec. 23, T. 1 S., R. 4 W.		do	1,007	1,007	100	Artesian			.083	Do.
249	S. B. Parish	Sec. 14, T. 1 S., R. 4 W.	1892	10-inch pipe	1,019	1,019	540	do	2,500		.40	Irrigation.
250	do	do	1885	6-inch pipe	1,017	1,015	104		300			
251	do	do	1889	2-inch pipe	1,016		100		150			
252	do	do	1870	1¼-inch pipe	1,014	1,014	83	Artesian			.004	
253	Mrs. Elizabeth Case	do	1898	3-inch pipe	1,007	1,007	91	do	85		.115	Irrigation; domestic.
254	do	do	1892	7-inch pipe	1,009	1,009	260	do	500		.2	Irrigation.
254*a*	W. G. Merrilees	do	1893	do	1,009	1,009	211	do			.14	Do.
254*b*	do	do	1897	3-inch pipe	1,009	1,009	86	do			Small.	Do.
255	Wm. Stewart	Sec. 15, T. 1 S., R. 4 W.	1898	8-inch pipe	1,004	1,004	315	do			[a] 1.14	Do.
256	do	do	1898	9-inch pipe	1,005	1,005	85	do			[b] .2	Do.
257	do	do		1¼-inch pipe	1,004	1,004		do			Small.	Domestic.
259	do	do		7-inch pipe	1,002							Irrigation.
260	John Sullivan	Sec. 14, T. 1 S., R. 4 W.	1874	2-inch pipe	1,021				100		([c])	Irrigation; domestic.
261	do	do	1893	3-inch pipe	1,024	1,024	210	Artesian	325		.062	
263	do	do	1884	7-inch pipe	1,025	1,023	84		80		([d])	
264	do	do	1871	2-inch pipe	1,037		90				([d])	
265		do	1892	do	1,022		92	Artesian			.002	Domestic.
266	Wm. Baker	do	1870	1.5-inch pipe	1,022	1,022	96	do	130		Small.	Do.

267	.....do	.....do	1899	3-inch pipe	1,024	1,024							gation.
268	P. J. Clevenger	.....do		2-inch pipe	1,030			10 electric; centrifugal			(e)		
269	.....do	.....do	1897	10-inch pipe	1,043		150				.5	Irrigation.	
270	Henry Warren	.....do	1883	2-inch pipe	1,033	1,023	106		150		(d)		
271	.....do	.....do	1890	3-inch pipe	1,033	1,023	100	12 wind	100	$160	(d)	Domestic; irrigation.	
272	John Sullivan	.....do	1898	.....do	1,024	1,024	214	Artesian	300		.178	Irrigation.	
273	Henry Warren	.....do	1880	7-inch pipe	1,036	1,026	106		200		(e)	Not used.	
274	.....do	.....do	1880	.....do	1,038	1,028	220		500		(f)	Do.	
275	.....do	.....do	1893	10-inch pipe	1,039	1,039	640	Artesian	3,000		.386	Irrigation.	
276	Frank Feri	.....do		2-inch pipe	1,034			Hand			(g)	Domestic.	
277	G. Renwick	Sec. 8, T. 1 S., R. 4 W.		6-inch pipe	1,090	1,055	186	8 wind			Small.	Do.	
278	Orange Land and Water Co.	.....do		7-inch pipe	1,089	1,069	225	Centrifugal; 20 compressor; 3 wells in group together.			1.64	Domestic; irrigation.	
279	Callahan estate	Sec. 20, T. 1 S., R. 4 W.	1886	Dug, 4 by 4 foot	1,009	933	84	12 wind					
280	E. Memory	.....do	1886	.....do	982	927	60	.....do			Small.	Domestic.	
281	F. A. Cleveland	Sec. 8, T. 1 S., R. 4 W.	1898	2-inch pipe	1,072		90	8 wind	47	40	Small.	Do.	
282	C. H. Westmyer	.....do	1897	3-inch pipe	1,069	1,062	94	.....do	74	100	Small.	Domestic; irrigation.	
283	W. W. Brison	Sec. 9, T. 1 S., R. 4 W.	1899	2-inch pipe	1,062	1,052	99	10 wind	100	200	Small.	Domestic.	
284	G. F. Woods	.....do	1900	8-inch pipe	1,059	1,049	140	.....do	300	350	.008	Domestic; irrigation.	
285	.....do	.....do	1887	7-inch pipe	1,060	1,060	300				None.		
286	City of Colton	Sec. 8, T. 1 S., R. 4 W.		10-inch pipe (2) 7-inch pipe (2)	1,065		200 640	Centrifugal; 20 electric		2,000	2.500	Do.	
287	Isaac Jameson	.....do	1898	8-inch pipe	1,070	1,050	90	12 wind	126	275	.015	Do.	
288	J. Collins	.....do	1887	3-inch pipe	1,054		75	10 wind			Small.	Irrigation; domestic.	
289	J. C. Ralphs	Sec. 9, T. 1 S., R. 4 W.	1899	10-inch pipe	1,047	1,016	202	12 wind	500	200	Small.	Do.	
290	Los Angeles Building Co.	.....do	1893	.....do	1,052		160	8 gas; centrifugal			.8	Irrigation.	
291	V. Herkelrath	Sec. 15, T. 1 S., R. 4 W.	1882	2-inch pipe	979	979		Artesian	70		.072	Domestic.	
292	.....do	.....do	1880	.....do	980	980		.....do	175		.119	Irrigation.	
293	Mrs. Nowland	.....do	1875	.....do	980	980	160	.....do	275			Do.	

a 1899. b 1898. c Stopped flowing in 1895. d Stopped flowing in 1898. e Stopped flowing in 1889. f 1890. g May, 1900.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
294	M. H. Hurd	Sec. 15, T. 1 S., R. 4 W.	1887	2-inch pipe	983			Artesian				Domestic.
295	Mrs. N. H. Ball	do	1894	7-inch pipe	996	996	253	do	$500		.262	Irrigation.
296	Los Angeles Building Co.	Sec. 9, T. 1 S., R. 4 W.		10-inch pipe	1,051	1,049	446	do			.4	Do.
297	do	do		do	1,050	1,048	451	do			.4	Do.
298	Mrs. N. H. Ball	Sec. 15, T. 1 S., R. 4 W.	1886	3-inch pipe	992	992	107	do	250			Domestic.
299	W. Beck	do	1892	do	998	988	204	do				Irrigation.
300	H. Kleuter	Sec. 10, T. 1 S., R. 4 W.	1885	do	1,006	1,006	200	do	300		.074	Domestic; irrigation.
301	do	do	1887	do	1,005	1,005	206	do	328			Irrigation.
302	do	do	1887	do	1,005	1,005	132	do	159		.518	Do.
303	do	do	1897	do	1,003	1,003	135	do	125		.006	Do.
304	Stephen Wood	Sec. 11, T. 1 S., R. 4 W.	1894	do	1,010	1,010	160	do			Small.	Domestic.
305	W. B. Barton	Sec. 14, T. 1 S., R. 4 W.	1883	2-inch pipe	1,041		100	12 wind		$216	Small.	Do.
306	Stephen Wood	Sec. 11, T. 1 S., R. 4 W.	1880	3-inch pipe	1,022		164	8 wind			Small.	Stock.
307	F. M. Kellar	do	1882	do	1,024	1,024	267	Artesian	500		.02	Domestic.
308	W. B. Barton	Sec. 13, T. 1 S., R. 4 W.	1892	10-inch pipe	1,045	1,033	115	9 gas; centrifugal			.209	Irrigation.
309	A. J. Downer	do		3-inch pipe	1,045		190	12 wind	125	50	Small.	Domestic.
310	Edwin Martin	do		do	1,045	1,033	215	Hand			Small.	Do.
311	Lucas Hoagland	do	1897	2-inch pipe	1,049	1,039	80	do	75		Small.	Do.
312	do	do	1884	3-inch pipe	1,050	1,040	250	8 wind	250	75	Small.	Stock.
313	do	Sec. 12, T. 1 S., R. 4 W.	1884	2-inch pipe	1,047		100		100			Not used.
314	R. F. Garner	Sec. 10, T. 1 S., R. 4 W.	1888		1,019		200	Artesian			Small.	Domestic.
315		Sec. 12, T. 1 S., R. 4 W.		10-inch pipe	1,059	1,059	682+	do			.123	Stock.
316	Geo. M. Cooley	Sec. 36, T. 1 N., R. 4 W.	1892	7-inch pipe	1,150	1,108	66	12 wind		500		Irrigation; domestic.
317	do	do	1895	11-inch pipe	1,150	1,108	80	9 gas		1,500	.6	Irrigation.
317a	do	do	1895	10-inch pipe	1,150	1,108	80	9½ cylinder pumps				Do.

318	E. J. Stiles	Sec. 35, T. 1 N., R. 4 W.	1898	7-inch pipe	1,196	1,157	48	10 wind	40	160	Small.	Domestic; stock.
319	Jas. Dickson	do	1888	10-inch pipe	1,179	1,145	44	12 wind		135	Small.	Domestic.
320	J. G. Wood	do	1884	7-inch pipe	1,124	1,090	44	do		200	Small.	Do.
321	do	Sec. 36, T. 1 N., R. 4 W.	1885	11-inch pipe	1,140	1,092	64	Cylinder pump; 5 gas	240	600	.125	Irrigation.
322	M. E. Myers	Sec. 35, T. 1 N., R. 4 W.	1890	2-inch pipe	1,111	1,089	310	12 wind				Domestic; irrigation.
323	J. S. Bean	Sec. 3, T. 1 S., R. 4 W.	1889	3-inch pipe	1,108	1,108	210	Artesian	200		.1	Irrigation.
324	do	do	1898	10-inch pipe	1,108	1,108	524	do	1,100		.9	Do.
325	J. F. Johnson	Sec. 34, T. 1 N., R. 4 W.	1890	7-inch pipe	1,098	1,076	39	Hand				Not used.
326	Oscar Perris	Sec. 26, T. 1 N., R. 4 W.			1,177		96	Steam; power				Irrigation.
327	S. G. Ramsey	Sec. 25, T. 1 N., R. 4 W.	1896	10-inch pipe	1,190	1,125	90	Power; 10 gas	160	1,200	.3	Do.
328	Saml. S. Ford	Sec. 26, T. 1 N., R. 4 W.	1898	Dug, 3-foot diameter.	1,185	(a)	58	Wind		225	None.	
329	Muscupiabe Land and Water Co.	Sec. 23, T. 1 N., R. 4 W.	1899	10-inch pipe	1,288	1,143	402	Power; 15 steam	1,200	2,000	.5	Domestic; irrigation; stock.
330	do	Sec. 26, T. 1 N., R. 4 W.	1892	do	1,222	(a)	102	Wind	300	250	None.	
331	Mrs. Anne C. Severance	do	1895	do	1,227	(a)	106	12 wind	300	900	None.	
332	Mrs. S. A. Smith	Sec. 27, T. 1 N., R. 4 W.	1894	do	1,224	1,224	140	16 wind		800	.010	Irrigation; domestic.
333	F. M. Johnson	Sec. 34, T. 1 N., R. 4 W.	1899	10-inch pipe	1,117	1,095	600	10 gas; cylinder pump	1,160	800	.230	Irrigation.
334	do	do	1880	12-inch pipe	1,112	1,084	40	Wind			Small.	Stock; domestic.
335	H. H. Fitting	Sec. 35, T. 1 N., R. 4 W.	1885	7-inch pipe	1,124		44	do			Small.	Do.
336	do	do	1888	Dug, 6 by 6 foot	1,135	(a)	47	4½ gas; cylinder pump	100			
337	do	do	1886	3-inch pipe	1,131		325		1,000		Dry.	
338	C. Hansen	do	1895	7-inch pipe	1,127	1,090	39	8 wind		200	Small.	Do.
339	N. Hoien	do	1895	do	1,127	1,090	47				Small.	Do.
340	John Anderson	Sec. 34, T. 1 N., R. 4 W.	1885	do	1,130		90	8 wind	114	100	Small.	Do.
341	H. N. Stones	do	1884	do	1,141	1,087	85	do		125	Small.	Do.
342	M. F. Swing	do	1891	do	1,151		93	12 wind		220		Domestic; stock.
343	do	do	1894	do	1,152		87	do				Irrigation.
344	A. R. Togg	do	1891	do	1,160		100	do			Small.	Irrigation; domestic.
345	F. L. Smith	do	1897	do	1,163		106	10 wind	105	135	.002	Do.
346	John W. Anderson	do	1880	do	1,165	1,103	70	do	75	175	.002	Irrigation.

a No water.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
347	John W. Anderson	Sec. 34, T. 1 N., R. 4 W.	1900	7-inch pipe	1,166	1,103	113	16 wind	$125	$225	0.004	Irrigation.
348	S. E. Pearson	Sec. 27, T. 1 N., R. 4 W.	1899	do	1,182	1,107	104	12 wind	135	60	Small.	Irrigation; domestic.
349	R. Meacham	do	1900	do	1,183		110	do			Small.	Irrigation; stock.
350	do	do	1890	do	1,172	(a)	64	do			None.	
351	J. H. Taylor	do	1896	do	1,188	(a)	62	8 wind	50	100	None.	
352	W. G. Warner	do	1899	do	1,189	1,119	80	10 steam				Not used.
353	F. D. Olmstead	do	1895	do	1,190		101	12 wind		100	Small.	Irrigation; domestic.
354	S. F. Kelley	Sec. 28, T. 1 N., R. 4 W.	1897	do	1,170	1,121	115	8 wind			Small.	Do.
355	S. F. Kelley et al	do	1900	12-inch pipe	1,185	1,127	208	Electric; centrifugal	1,700	1,171	.9	Irrigation.
355a	do	do	1899	10-inch pipe	1,185	1,127	460					
356	H. C. Ward	do		7-inch pipe	1,177	1,118	120	12 wind			Small.	Do.
357	S. H. Johnson	do	1885	do	1,182	1,122	84	10 wind		250	Small.	Domestic.
358	H. Giddings	do	1898	do	1,205	1,148	73	15 wind		125		Do.
359	W. G. Rowland	do	1893	do	1,224	1,156	112	Geared pump; 3 gas	125	625	.1	Irrigation.
360	Fred Heilemann	Sec. 32, T. 1 N., R. 4 W.	1889	do	1,227	1,147	146	16 wind	200	750	.008	Irrigation; domestic.
361	do	do	1894	do	1,228	1,148	129	18 wind			.012	Do.
362	do	Sec. 29, T. 1 N., R. 4 W.	1890	10-inch, 8-inch, and 6½-inch pipes.	1,245	1,155	1,025		7,000		(b)	
363	B. E. Wheeler	do	1898	10-inch pipe	1,258	1,152	125	Plunger pump; 5 gas	300	800		Do.
364	F. Alvarado	Sec. 32, T. 1 N., R. 4 W.	1900	7-inch pipe	1,188	1,135	93					Not used.
365	A. B. Hancock	Sec. 5, T. 1 S., R. 4 W.	1896	do	1,170		56	12 wind	125	100	Small.	Domestic; irrigation; stock.
366	do	do	1882	do	1,169		76	do				Do.

367	D. W. White	Sec. 4, T. 1 S., R. 4 W.	1871	do	1,109	1,089	195	Gas; centrifugal; 8 wind.	1,200	200	.400	Irrigation; domestic.
368	W. F. Holcomb	Sec. 33, T. 1 N., R. 4 W.		do	1,115	1,089	37				Small.	Domestic.
369	Alex. Wixom	Sec. 4, T. 1 S., R. 4 W.	1899	8-inch pipe	1,117		45	12 wind	50	148	Small.	Do.
370	F. L. Holcomb	Sec. 33, T. 1 N., R. 4 W.	1885	7-inch pipe	1,128	1,100	47	do	100	150	Small.	Do.
371	do	do	1885	do	1,133	1,103	47	do	100	150	Small.	Stock.
372	J. J. Whitney	Sec. 4, T. 1 S., R. 4 W.	1884	Pipe	1,129	1,101	112	Wind		400	Small.	Domestic; stock.
373	P. B. Hockaday	do	1887	7-inch pipe	1,133		110	12 wind		500	Small.	Domestic; irrigation.
374	J. J. Morris, sr.	Sec. 5, T. 1 S., R. 4 W.	1890	8-inch pipe	1,137	1,109	53	10 wind		75	Small.	Do.
375	Dexter Field	do	1870	6-inch pipe	1,147	1,112	45	do			Small.	Domestic.
376	C. A. Muscott	Sec. 32, T. 1 N., R. 4 W.	1886	8-inch pipe	1,158	1,115	78	12 wind	100	250		Domestic; irrigation.
377	J. W. Roberts	Sec. 27, T. 1 N., R. 4 W.	1899	10-inch pipe	1,210	1,155	160	Plunger pump; 5 electric.	400	900	.24	Do.
378	T. C. Parker	Sec. 32, T. 1 N., R. 4 W.	1886	7-inch pipe	1,205	1,110	98	12 wind; 3 gas		550		Do.
379	P. Oldecker	Sec. 33, T. 1 N., R. 4 W.	1893	7-inch pipe	1,195		133	Geared pump; 2 gas		400	.10	Do.
380	A. Petersen	do	1890	do	1,192	1,134	76	12 wind	50	100	Small.	Do.
381	C. A. Bruckman	Sec. 32, T. 1 N., R. 4 W.	1894	10-inch pipe	1,221	1,151	146	Geared pump; 16 gas	325	775	.36	Irrigation.
382	do	do	1892	7-inch pipe	1,215	1,145	84	12 wind	115	300		Do.
383	do	do	1892	do	1,214	1,144	85	Geared pump; 5 gas	115	625	.042	Do.
384	do	do	1890	do	1,192	1,134	85	12 wind	115	250	Small.	Domestic.
385	Wilson & Wheat	do	1890	do	1,188	1,128	82	16 wind				Domestic; irrigation.
386	E. D. Palmer	Sec. 33, T. 1 N., R. 4 W.	1894	do	1,184		80	14 wind			Small.	Do.
387	C. G. Leonhardt	Sec. 32, T. 1 N., R. 4 W.	1890	do	1,182		85	12 wind	115	192	Small.	Do.
388	do	do	1899	8-inch pipe	1,197	1,133	90	do	125	297	.006	Irrigation.
389	S. E. A. Palmer	Sec. 33, T. 1 N., R. 4 W.	1887	7-inch pipe	1,176	1,124	92	14 wind	150	350	.003	Domestic; irrigation.
390	Fred F. Palmer	do	1899	Dug, 4 by 6 foot; 7-inch pipe.	1,189	1,134	85	Duplex; steam	300	500	.036	Irrigation.
391	W. D. Wilson	Sec. 32, T. 1 N., R. 4 W.	1893	8-inch pipe	1,203	1,138	94	12 wind				Do.
392	S. H. Harmon	do	1893	10-inch pipe	1,191	1,132	133	Geared pump; 5 gas	1,300	(c)	.020	Do.
393	S. W. Harmon	do	1882	7-inch pipe	1,181	1,128	83	12 wind	50	220		Domestic; irrigation.
394	J. O. Slatter	Sec. 33, T. 1 N., R. 4 W.	1890	do	1,155		100	do		150	Small.	Domestic.
395	C. N. Damron	do		do	1,120	1,093	47	8 wind			Small.	Do.

a No water. b Tools left in well. c Two wells.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
396	Mrs. Amy McCrary	Sec. 33, T. 1 N., R. 4 W.	1899		1,138	1,112	91	Hand			Small.	Domestic.
397	Thos. Webster	do	1898	7-inch pipe	1,134			12 wind				Do.
398	N. M. Swarthout	do	1885	do	1,142	1,115	75	8 wind	$150	$100	Small.	Do.
399	do	do	1895	10-inch pipe	1,169		80	Horse	100	85	Small.	Irrigation.
400	J. H. Lytle	do	1885	7-inch pipe	1,166	1,135	79	12 wind	75	50	Small.	Domestic; irrigation.
401	H. S. Davidson	do	1880	do	1,158		56	do		500		Do.
402	N. Swarthout	do	1885	do	1,142	1,108	55	8 wind			Small.	Domestic.
403	G. W. Evans	do	1887	6-inch pipe	1,128	1,096	75	do			Small.	Do.
404	R. M. Bradley	do	1884	7-inch pipe	1,101	1,082	90	12 wind			Small.	Do.
405	Mrs. Sarah Abel	do	1880	Dug, 3 foot diameter.	1,109	1,088	22	Bucket			Small.	Do.
406	R. Poppett	Sec. 34, T. 1 N., R. 4 W.	1885	7-inch pipe	1,109	1,085	45	12 wind	50	140	Small.	Domestic; irrigation.
407	G. Johnson	do	1890	do	1,114	1,087	47	8 wind	60	60	Small.	Do.
408	E. G. Fish	do	1889	2-inch pipe	1,133		425	do	1,000		Small.	Do.
409	C. Cohn	do		7-inch pipe	1,118	1,089		10 wind			Small.	Domestic.
410	O. B. Peck	do	1888	do	1,147		115	14 wind			Small.	Domestic; irrigation.
411	K. P. Stephens	do	1883	do	1,164	1,114	65	do			.003	Do.
412	Jno. Y. Anderson	do	1900	8-inch pipe 12-inch pipe	1,165	1,109	150 460		2,000			Not used.
413	Jno. Lawrence	do	1897	7-inch pipe	1,091	1,076	42	8 wind		160	Small.	Domestic.
414	J. C. Wees	do	1898	do	1,097	1,073	46	do				Do.
415	Thos. J. Rennous	do	1900	do	1,133	1,101	72	10 wind	72	150	Small.	Domestic; irrigation.
416	H. H. Ham	do	1888	do	1,121	1,090	52	8 wind	75	100	Small.	Do.
417	W. M. Jenkins	do	1884	do	1,118	1,088	52	12 wind			Small.	Do.

421	B. M. Wall	do	1897	3-inch pipe	1,100		137	8 wind	60	125	.002	Domestic; irrigation.
422	E. Case	Sec. 3, T. 1 S., R. 4 W	1899	8-inch pipe	1,086	1,073	50	Hand			Small.	Do.
423	Jno. E. Garner	Sec. 2, T. 1 S., R. 4 W	1900	do	1,087	1,073	334	Centrifugal; 8 gas	750	750	.800	Domestic.
424	do	Sec. 35, T. 1 N., R. 4 W	1888	10-inch pipe; 7-inch pipe.	1,164	1,108	420	Centrifugal; 20 electric	1,500	3,000	1.200	Irrigation, etc.
425	Colton City Water Co	Sec. 31, T. 1 N., R. 4 W	1900	10-inch pipe	1,202		208	Centrifugal; 25 gas			1.480	Irrigation.
426	San Bernardino city waterworks.	Sec. 36, T. 1 N., R. 5 W	1895	Two 11-inch pipes			320 550	Centrifugal; 25 gas			1.400	Irrigation; domestic.
			1900	12-inch pipe	1,239	1,207	800					City supply.
427	Riverside Highlands Water Co.	Sec. 31, T. 1 N., R. 4 W	1900	10-inch pipe	1,218	1,204	320					Not used.
428	do	Sec. 36, T. 1 N., R. 5 W	1892	do	1,246	1,211	650	Centrifugal; 22 gas	5,000	1,100	1.600	Irrigation; domestic.
429	do	Sec. 31, T. 1 N., R. 4 W	1893	Two 10-inch pipes	1,250	1,201	350 300	Centrifugal; 30 electric	3,000	2,500	2.000	Do.
430	do	do		do	1,258	1,203	500–600	do	3,000	2,500	2.800	Do.
431	Rialto irrigation district Citizens' Water Co.	Sec. 36, T. 1 N., R. 5 W	1891	do	1,255	1,204	450	Centrifugal; turbine	1,500		1.300	Do.
432	do	do	1894	10-inch pipe	1,260	1,207	460	Centrifugal; 20 gas	1,800	6,000	.720	Do.
433	F. E. Watkins	do	1888	do	1,266	1,210	621	Two 25 compressors			890	Irrigation.
434	Lytle Creek Water and Improvement Co.	do	1900	Three 12-inch pipes.	1,290	1,215	226	Duplex steam	3,661	3,500	2.200	Do.
435	Rialto irrigation district	Sec. 25, T. 1 N., R. 5 W	1897	10-inch pipe	1,333	1,303	520	Centrifugal; 30 electric	1,500	2,000	1.800	Irrigation; domestic.
436	do	do	1894	do	1,342	1,306	432	do	1,500	2,000	1.500	Do.
437	Anglo-American Canaigre Co.	do	1899	Dug, 7 by 9 foot (2).	1,337	1,307	45					Not used.
438	F. E. Watkins	do	1898	10-inch pipe	1,390	1,251	381		2,000			Do.
439	Riverside Highlands Water Co.	Sec. 31, T. 1 N., R. 4 W		20 wells	1,200–1,225						(a)	Irrigation.
440		Sec. 4, T. 1 S., R. 4 W		Dug, 4 by 4 foot	1,089	1,083	7	Hand				Stock.

a These 20 wells have nearly all ceased flowing.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Elevation of surface.	Elevation of water, 1900.	Depth of well.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
					Feet.	*Feet.*	*Feet.*				*Sec.-ft.*	
441	M. E. Brooks	Sec. 5, T. 1 S., R. 4 W.	1886	3-inch pipe	1,102		132	8 wind				Domestic; stock; irrigation.
442	do	do		do	1,105		140	12 wind			Small.	Irrigation.
443	Mrs. Mary Bemis	do	1888	Pipe	1,113		132	Hand			Small.	Domestic.
444	A. W. Bemis	do	1890	8-inch pipe	1,118	1,101	48	12 wind			Small.	Do.
445	do	do	1894	10-inch pipe	1,114	1,104	50	Centrifugal; 3 gas		$250	0.014	Irrigation.
446	D. F. Probst	Sec. 4, T. 1 S., R. 4 W.	1886	7-inch pipe	1,085	1,070	36	10 wind			Small.	Domestic.
447	Mrs. A. Tompkins	Sec. 5, T. 1 S., R. 4 W.	1882	do	1,115		212	Wind	$1,000	175	Small.	Domestic; irrigation.
448	J. Hancock	do	1875	do	1,138	1,092	128	do			Small.	Do.
449	M. D. Reynolds	do	1900	10-inch pipe	1,136	1,106	146	Centrifugal; 25 gas	300	1,400	.027	Irrigation.
450	do	do	1898	7-inch pipe	1,116	1,094	40	8 wind	60	150	Small.	Domestic.
451	Mrs. M. Lord	Sec. 4, T. 1 S., R. 4 W.	1888	3-inch pipe	1,125		150	10 wind			Small.	Do.
452	John Marshall	Sec. 5, T. 1 S., R. 4 W.	1888	7-inch pipe	1,128	1,103	42	do			Small.	Do.
453	I. W. Hazlett	Sec. 4, T. 1 S., R. 4 W.	1900	do	1,101	1,082	142	12 wind	233		.002	Do.
454	Mrs. Alice Wixom	do		do	1,067	1,055	22	do			Small.	Do.
455	Mrs. Irving	do		do	1,099	1,078	100	8 wind			Small.	Do.
456	J. B. Kitring and R. H. Hacker.	do	1895	2-inch pipe	1,085	(a)	152	do		260	Small.	Do.
457	J. F. Cadd	do	1888	7-inch pipe	1,068	1,057	40	Hand	40		Small.	Do.
458	H. E. Gardner	Sec. 5, T. 1 S., R. 4 W.		3-inch pipe	1,089	1,075		8 wind			Small.	Do.
459	Mrs. Marilla Smith	do	1889	2-inch pipe	1,094	1,079	122	Wind	122	150	Small.	Do.
460	San Bernardino County Hospital.	Sec. 8, T. 1 S., R. 4 W.	1898 1899	3-inch pipe 7-inch pipe 10-inch pipe	1,089	1,071	125 125 330	Centrifugal; 6 gas			.300	Irrigation.
461		do		2 wells	1,057			Electric				Do.

462	Riverside Trust Co.	Sec. 26, T. 1 S., R. 4 W.		9 wells	1,019	1,019		Artesian					Irrigation.
463	Riverside Water Co.	Sec. 2, T. 1 S., R. 4 W.			1,036	1,036		do				1.976	Do.
464	do	do			1,037	1,037		do				1.930	Do.
465	do	do	1900	10-inch pipe	1,040	1,040	544	do				2.896	Do.
466	do	do	1900	do	1,041	1,041	582	do				3.096	Do.
467	E. D. Meissner	Sec. 26, T. 1 S., R. 4 W.	1899	10 and 8 inch pipes	1,200	1,120	500	Plunger pump; 20 gas	2,600	1,350	.200		Do.
468	G. G. Lathrop	do	1897	7-inch pipe	1,063	1,017	70	10 wind	105	130	.003		Domestic; irrigation.
469	R. L. Dewitt	do	1897	Dug	1,047	1,028	26	Hand					Domestic.
470	Charles Morris	do	1892	Dug, 12 by 12 foot, 10-inch pipe.	1,078	1,063	80	12 wind	400	140	.007		Irrigation.
471	do	do	1899	10, 8, and 7 inch pipes.	1,077		640	Artesian	1,500		.005		
472	No record.												
473	F. S. Waters	Sec. 23, T. 1 S., R. 4 W.	1877	2-inch pipe	1,054	1,044	196	8 wind	200	145	.002		Domestic; irrigation.
474	J. H. Hatherley	do	1888	3-inch pipe	1,555		450	Artesian	1,700		.140		Irrigation.
475	J. H. Kelly	do	1890	8-inch pipe	1,089		382	do	2,000		.400		Domestic; irrigation.
476	do	do	1891	7-inch pipe	1,074	1,066	500	Hand		5			Domestic.
477	Mr. Meyers	Sec. 25, T. 1 S., R. 4 W.	1890	do	1,060		400				(b)		
478	W. E. Pedley	Sec. 2, T. 1 S., R. 4 W.	1899	10-inch pipe	1,042		510	Artesian	1,284		2.700		Irrigation.

a 1,070 feet in 1899.

b Stopped flowing in 1899.

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[Water-Supply Paper No. 142.]

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3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the forty-fifth in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

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WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls.
WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls.
WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.
WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp.
WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls.
WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls.
WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp.
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WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96-140 pp.
WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp.
WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls.
B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.
WS 77. Water resources of Molokai, Hawaiian Islands, by W. Lindgren. 1903. 62 pp., 4 pls.
WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.
PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
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WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.
PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls.
WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.
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WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.
WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.
B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.
WS 120. Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879-1904, by M. L. Fuller. 1905. 128 pp.
WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.
WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.
WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. — pp., 24 pls.
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PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905.
WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.
WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.
WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 8 pls.
WS 140. Field measurements of the rate of movement of underground water, by C. S. Slichter. 1905.
WS 141. Observations on the ground waters of the Rio Grande Valley, 1904, by C. S. Slichter. 1905.
WS 142. The hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 12 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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SEPTEMBER, 1905.

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

EXPERIMENTS

ON

STEEL-CONCRETE PIPES ON A WORKING SCALE

BY

JOHN H. QUINTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., March 25, 1905.

SIR: I transmit herewith a manuscript by John H. Quinton, supervising engineer of the Reclamation Service, entitled "Experiments on Steel-Concrete Pipes on a Working Scale," and request that it be published as one of the series of Water-Supply and Irrigation Papers.

The use of concrete as a substitute for stone and metal in connection with engineering projects has, during the last few years, become well-nigh universal. One of the most important fields of engineering investigation is that of determining the durability and permanence of concrete structures, especially those erected in connection with water supplies. The investigations reported in the accompanying manuscript are therefore of peculiar significance, and the results promise to be of great value.

Mr. Quinton's experiments have been made upon large pipes, and the results are therefore applicable for use in practical engineering work. Heretofore similar investigations have been made on a small scale, and the conclusions which have been drawn from them are, as shown in the accompanying paper, erroneous in many respects.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

EXPERIMENTS ON STEEL-CONCRETE PIPES ON A WORKING SCALE.

By John H. Quinton.

INTRODUCTION.

Preliminary surveys of many irrigation projects in the arid States have shown that pressure pipes or, as they are often called, "inverted siphons," will be necessary for the economical construction of some of the works contemplated by the Reclamation Service. Hitherto such pipes have been made of iron or steel, or of wood staves bound with iron or steel rods. During the last few years the manufacture of steel has been so improved that steel has entirely replaced iron in all important structures. Therefore the choice of material for pressure pipe has been limited to the two materials, steel and wood.

In all of the reclamation projects it is most important that the structures on the main canals shall be of a permanent nature. The works have to be maintained for several years by the Reclamation Service before they are turned over to the people of the district. They are to be paid for in ten annual installments, and at the end of ten years they should be in good repair and as sound and durable as when they were constructed. This condition is a difficult one to fulfill.

STEEL PIPE.

Steel pipe is naturally limited to a thin shell on account of its great strength, weight, and cost. It is easily attacked by salts and acids, both on the inside by the water flowing through it and on the outside by the material surrounding it. A slight deterioration in so thin a shell means a large loss in strength, and the life of a steel pipe is therefore limited to a few years, depending upon the nature of the material in which it is laid. Experience has shown that in alkali ground in southern California the life of sheet-steel pipe is short. The life of the pipe may be lengthened by a coating, both inside and outside, of asphaltic material. The coating is applied by dipping the pipe into a hot bath of the asphalt mixture. If this dipping is not carefully done at just the proper temperature it is not likely to add

much to the life of the pipe. The coating is liable to be broken in places by careless handling in transit from the factory to the work, and unless such places are recoated they are soon attacked, and the efficiency of the pipe is thus materially lessened. In all of the projects in the arid States more or less alkali ground is encountered, and in many of the projects provision has to be made for the drainage of the lands to get rid of the alkali. Under these circumstances other and more durable material than steel or iron must be sought.

WOODEN PIPE.

Wooden pipes are now very extensively used for carrying water under pressure, and they have many advantages over steel. Large wooden pipes, however, must necessarily be made of longitudinal staves, bound and held in place by steel rods on the outside. The wood is porous and is soon filled with the water under pressure, and this makes the wooden part of the pipe practically safe from decay when it is protected from the rays of the sun either by a layer of earth or a light roof. The pipe must be filled with water at all times, however, to maintain the condition of saturation which is necessary for its durability. In a cold climate, such as that found in Montana, Wyoming, and the Dakotas, it would be unwise to keep a pipe full of water in the winter time when it is not in use for irrigation. Freezing weather would certainly affect the pipe injuriously unless it were buried in the ground deep enough to be unaffected by frost. The entire bursting strength of a large wooden pipe is derived from the steel bands or rods with which it is bound, and these, when buried underground, are then exposed to the same destructive agencies which attack the steel pipe. The form of the bands, however, being generally circular in section, gives them a longer lease of life than the thin shell of metal in a steel pipe; for this reason a wooden pipe is certainly a great improvement on a steel pipe.

Wooden pipes also have their limitations. They are fragile and easily broken by a blow from the outside and should never be used where they may be exposed to falling rocks or small landslides. If they are laid on the surface and exposed to the rays of the sun, the wood in the upper half of the pipe soon decays from alternate wetness and dryness, caused by different temperatures in sunshine and shade. In the heat of the sun the upper part of the pipe is dried rapidly, and during the night the pressure and capillary action force the water to the surface, to be dried out again the next day. This action may be counteracted in warm climates by building a roof over the pipes, but in cold climates the pipe must be emptied before frost sets in and allowed to remain empty all winter. This, again, subjects the pipe to alternate wetness and dryness, although at longer intervals; it also allows the staves to shrink in the winter time, and when the water is

turned into the pipe, and before the wood has had time to swell, sand and grit are forced into the seams between the staves, and the pipe becomes leaky and unserviceable.

In view of all these conditions, it was thought advisable to examine into the merits of steel concrete as a material for pressure pipes in the place of steel or wood.

STEEL-CONCRETE PIPE.

There is little doubt that steel concrete is a much more durable material than either steel or wood, but at the very outset it presents a serious drawback. Concrete is porous; and while theoretically it might be composed of such material as would render it impervious to water under ordinary pressures, practically it is found to be very difficult to make it so.

Many statements have been made as to the waterproof qualities of certain mixtures for concrete, but water under pressure is a very searching agent, and it must be admitted that so far as these experiments have gone such statements have not been substantiated. To determine just how much pressure of water ordinary well-made concrete would stand without leaking seriously, and what mortars would most effectually stop leaking, and up to what pressure, these experiments were undertaken.

It was recognized that experiments with small pipes would not be of such practical value as those with pipes of sizes more nearly commensurate with the work in hand. It was finally decided to make seven or eight pipes, each 5 feet in diameter inside and 20 feet long, with a 6-inch thickness of concrete shell, inclosing an armor of steel rods sufficient to resist a head of 150 feet of water with a factor of safety of 4. The quantities of water to be carried in the different projects vary from 250 to 1,500 second-feet, and this size seemed as small as it would be advisable to experiment with in order to show the practical difficulties of construction, as well as the flaws and imperfections in the pipe arising from careless or defective workmanship.

Water under pressure tells the truth without fear or favor, and a careful reading of these pages will show that there are many practical difficulties to be overcome in the construction of steel-concrete pipe, and that the most careful attention to details and rigid inspection and supervision are necessary to produce a steel-concrete pipe that will stand 100 feet of head of water without appreciable leakage.

COMPOSITION AND CONSTRUCTION OF PIPES.

Experience with concrete structures has shown that with nearly all kinds of cement there is an efflorescence deposited on the surface of the concrete wherever there is sufficient water back of the wall to force this efflorescence to the surface. This is due to the permeability of

the concrete and the passage of the water through it. Small particles of lime or cement are carried to the surface and deposited in the form of white powder.

There is also found in concrete a pulpy, gelatinous fluid, called by the French "laitance," from its milky appearance. Whenever water is forced through concrete this substance is deposited freely on the surface.

The entire subject of porosity and permeability of mortar and concrete has been very ably treated by M. R. Feret, chief of the Boulogne laboratory of the Ponts et Chaussées, in a paper published in the Annales des Ponts et Chaussées, July, 1892, and a most interesting discussion of the subject by American engineers is to be found in the Proceedings of the American Society of Civil Engineers, vol. 29, No. 6. In this discussion Mr. R. W. Lesley suggested that an addition of slaked lime to the concrete of which the pipe is composed might aid in making the mortar impermeable. Some of the pipes tested have been made with this addition. Mr. Lesley also referred to a paper by Messrs. J. B. McIntyre and A. L. True on The Permeability of Concrete under High Water Pressures. Some of the conclusions drawn from the experiments made by these gentlemen are, however, rather sweeping.

In the second paragraph of these conclusions it is stated that concretes composed of mixtures of cement, sand, and rock in the proportions of 1:2½:4 were impermeable under heads varying from 20 to 80 pounds per square inch, and in the last paragraph the following statement is made:

> It is perfectly safe to conclude that a concrete of the proportions of any of the specimens which did not leak under 80 pounds pressure would be practically impermeable under any condition ordinarily found in practice.

This seems a rather hasty conclusion, as the following pages show that many of the conditions ordinarily found in practice render it almost impossible to make a long and large concrete pipe impermeable. It is far from the intention of the writer to belittle in any way laboratory experiments, but great care must be exercised in drawing conclusions, especially in generalizing from particulars.

To determine just how a steel-concrete pipe, made by ordinary workmen in the usual practical way, would act under pressure was one of the main objects of these experiments.

It was decided to make seven pipes, with different proportions of sand, gravel, cement, lime, and waterproof material, with steel armor sufficient to resist a head of 150 feet of water, with a factor of safety of 4, under such conditions as would be found in most of the projects under consideration by the Reclamation Service, these conditions being well understood by the writer, who had visited the various localities and was familiar with them. It was not intended or supposed that

the experiments would cover a range great enough to exhaust the subject of impermeable concrete or mortar, but it was presumed that they would indicate the best mixtures and the limit of pressure which it would be wise to fix for actual work in the field, where pipes may be 3,000 or 4,000 feet in length and of large diameter.

COMPOSITION OF TEST PIPES.

The composition and dimensions of the test pipes are given below. All measurements were made loose, in boxes, just as they would probably be made in the field. These pipes were all made by workmen skilled in making concrete, who had been employed by a concrete contractor in Los Angeles. The work was supervised by the writer and by Mr. W. H. Sanders, consulting engineer of the Reclamation Service, one of whom was present at all times during the construction of the pipes.

Pipe No. 1.

Inside diameter, 5 feet; length, 20 feet; thickness, 6 inches; steel armor, 71 welded rings of three-fourths-inch round steel, and eight longitudinal steel rods one-half inch in diameter. In all pipes except No. 7 the armor was placed in the center of the shell.

Material used for concrete for pipe No. 1.

	Parts.
Cement, Gillingham	1
Sand—clean river sand—fine to coarse	2
Gravel refused on screen of 1¼-inch mesh and passing through 2½-inch mesh	2.5
Gravel refused on screen of half-inch mesh and passing through 1¼-inch mesh	2.5
Water	1.1

In this pipe 169 cubic feet of concrete in place required 214 cubic feet of solid materials, measured loose, or 243.2 cubic feet of solids and liquid. This pipe required 0.88 barrel of cement to one cubic yard of concrete.

Pipe No. 2.

Dimensions and armor same as No. 1.

Material used for concrete for pipe No. 2.

	Parts.
Cement, Gillingham	1
Sand	2
Gravel refused on 1-inch mesh and passing through 2½-inch mesh	1.6
Gravel refused on half-inch mesh and passing through 1-inch mesh	1.6
Water	.8

In this pipe 169 cubic feet of concrete required 243.75 cubic feet of solid materials, measured loose. This pipe required 1.27 barrels of cement to 1 cubic yard of concrete.

Pipe No. 3.

Dimensions and armor same as No. 1. Half of the water used in the construction of this pipe was mixed with soap in proportion of

one-half pound of soap to 1 gallon of water, and the other half was mixed with 1 pound of alum to 4 gallons of water. The materials are in the following proportions:

Material used for concrete for pipe No. 3.

	Parts.
Cement, Ideal	1
Sand	2
Gravel, half-inch mesh	3.2
Water	1

In this pipe 169 cubic feet of concrete in place required 234 cubic feet of solid materials, measured loose, or 272 cubic feet of solids and liquid. This pipe required 1.6 barrels of cement to 1 cubic yard of concrete in place.

PIPE NO. 4.

Dimensions and armor same as No. 1.

Material used for concrete for pipe No. 4.

	Parts.
Cement, Ideal	1
Sand	2
Gravel, all half-inch mesh	4
Water	.96

In this pipe it required 247 cubic feet of solids, measured loose, or 281 cubic feet of solids and liquid to make 169 cubic feet of concrete in place. This pipe required 1.4 barrels of cement to 1 cubic yard of concrete in place.

PIPE NO. 5.

Dimensions and armor same as No. 1.

Material used for concrete for pipe No. 5.

	Parts.			Parts.
Lime paste	1	or	Cementing material	1
Cement, Ideal	2		Sand	2
Sand	6		Fine gravel	4
Fine gravel	12			

This pipe required 223 cubic feet of solids and paste, measured loose, to make 169 cubic feet of concrete in place. The amount of water used was not measured. This pipe required 0.84 barrel of cement and 81 pounds of lime paste to 1 cubic yard of concrete in place.

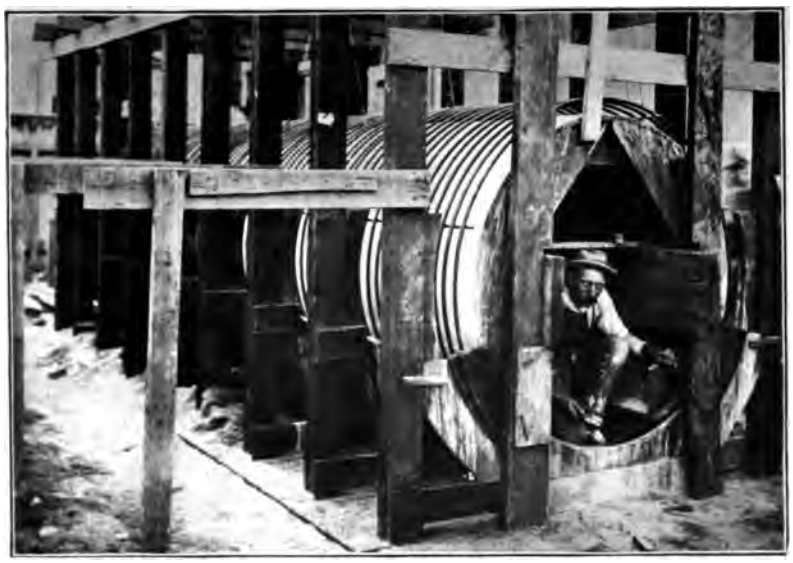
PIPE NO. 6.

Dimensions and armor same as No. 1.

Material used for concrete for pipe No. 6.

	Parts.			Parts.
Cement, Gillingham	1	or	Cementing material	1
Lime	1		Sand	2
Sand	4		Small gravel	4
Water	2		Water	1

A



B

METHOD OF PIPE CONSTRUCTION.

This pipe required 252 cubic feet of solids, measured loose, and 288 cubic feet of solids and liquid to make 169 cubic feet of concrete in place. It had 0.63 barrel of cement and 128 pounds of lime to 1 cubic yard of concrete in place.

PIPE No. 7.

Inside diameter, 5 feet; thickness of shell, 6 inches; length, 20 feet; steel armor composed of 41 pieces of half-inch, round, welded steel rod, held in place by 8 steel rods one-half inch in diameter and 20 feet in length. This armor is set 1¾ inches from inside of shell.

Material used for concrete for pipe No. 7.

	Parts.			Parts.
Cement, Ideal	1	or	Cementing material	1
Lime paste	½		Sand	2
Sand	3		Small gravel	4
Small gravel	6			

This pipe required 262 cubic feet of solids and paste to make 172 cubic feet of concrete in place. It was made with the intention of testing the elastic limit of the steel and concrete together as compared with the elastic limit of the steel alone, but it will be seen from a perusal of the experiments that this was impracticable on account of the leakage.

METHOD OF PIPE CONSTRUCTION.

The method of construction shown in Pl. I may be briefly described as follows:

Nine rectangular frames of 4- by 6-inch rough pine lumber are first set up on the line of the pipe, about 2½ feet from center to center. These frames are about 7 feet in width inside and 8 feet in height.

The sills of these frames are cut out to the form of the lower seventh of the outside surface of the pipe, and are sunk into the ground until the upper ends of the arcs are even with the surface of the ground. The frames are then steadied and braced in their true line, and the material of the ground surface is removed to the form of the lower part of the outside surface of the pipe, as indicated by the buried sills.

Tarred paper is now laid over this surface to prevent undue absorption of moisture from the cement by the earth or by dry material.

A long sill is then laid on top of the frames on center line, as shown in Pl. I, *A*, and from this the steel armor is suspended and held in place by a few small blocks, which are removed as the concrete work reaches them. The wooden form for the inside surface of the pipe is now placed inside the pipe in four sections and nailed together with intersecting chord pieces to form the upper six-sevenths of the 5-foot circle. This form is then supported inside, in its true position, by two pieces of 2- by 12-inch plank the full length of the pipe and extending

beyond it at the ends. These planks are supported on two vertical pieces of 2- by 8-inch timber notched and held in place by spiking to the end frames.

This arrangement is exhibited in Pl. I, *B*, which shows the inside form and steel armor all ready for commencing the concrete work.

The first batch of concrete is laid on the tarred paper on the surface of the ground. This concrete has to be carried in buckets, and deposited quickly, and tamped through and under the steel armor for the full length of the pipe. Special tampers are made to fit between the rings and care is taken to keep the rings in their proper position until they are thoroughly covered with concrete. A wooden templet of the shape of the inside of the pipe is fixed at each end to guide the workmen in shaping the inside surface of the lower one-seventh of the

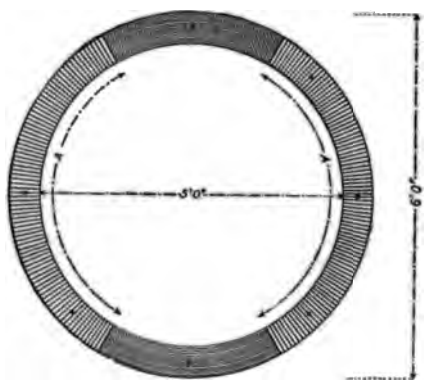


FIG. 1.—Diagrammatic section of pipe, showing directions of tamping.

pipe. This templet is plainly seen in front of Pl. I, *B*; the workman's trowel is pointing directly to it. The two lower sections of the outside form are also in place, so that as soon as the inside seventh of the pipe is completed the concrete can be run in and tamped from the outside and the work of laying it can be carried on continuously until the pipe is completed.

When the concrete has reached the top of these sections, another section of the outside form is added on each side, and so on until the upper part of the pipe is reached, where there is no longer any necessity for an outside form. The sections of the outside form are seen piled up in the foreground of Pl. I, *A*, and the method of fastening them to the outside frames is shown clearly in Pl. I, *B*.

The lower seventh of the pipe is tamped from the inside of the pipe in the direction of the pressure, and the upper eighth of the pipe is tamped from the outside in a direction opposite to that of the pressure. The remainder of the pipe (marked A, A, in fig. 1) is tamped in a direction normal to that of the pressure, or in what may be called a "circumferential direction."

A. METHOD OF FINISHING PIPE.

B. PIPE WITH DISKS SET READY FOR TEST.

The experiments show a marked difference in the degree of permeability of the concrete when tamped in these different directions.

All of the pipes were made on the same spot, as shown by framework in Pl. I, *A*, and when hard enough were rolled over to left and right alternately, to give room for the construction of the next pipe.

Each pipe was kept wet, both inside and outside, for at least one week after completion, and the last three pipes were, in addition, covered with canvas to protect them from the rays of the sun.

The concrete was all mixed by hand in the following way:

In the case of sand, cement, and gravel, the sand and cement, after loose measurement in boxes, was first shoveled over three times dry; the gravel was then added and the entire mass turned over twice dry and three times wet, the last time with a hoe. It was then shoveled into buckets and wheelbarrows and laid in the pipe, where it was thoroughly tamped. The buckets were used for the lower seventh of the pipe; the wheelbarrows were used for the sides and top of the pipe.

Pl. II, *A*, shows method of finishing upper part of pipe.

In the case of sand, cement, gravel, and lime paste (pipe No. 5) the paste was measured in boxes in the same way as the other materials, and the mass mixed just as before; but in the case of pipes Nos. 6 and 7 the lime paste was mixed with the water, and the lime water was used for wetting down the concrete during the process of mixing.

The work was all done in a careful and painstaking manner, as nearly as possible in the way in which it would be done on any ordinary piece of work in the field, under careful supervision and inspection. The first pipe of this series was completed on August 29, 1903, and the last pipe, No. 7, was completed on October 17, 1903. In the meantime all of the finished pipes were kept well wet, both inside and outside, so that they were thoroughly seasoned when the tests were commenced.

The pipes were all carefully squared up, and true planes were made at the ends with mortar composed of one part cement to one part sand, with a small quantity of lime paste to retard setting. This was done to make as perfect a joint as possible between the cast-iron ends used in testing and the pipe itself.

APPARATUS USED FOR TESTING PIPES.

To fill the pipes with water and make the ends tight under pressure two cast-iron disks, with suitable reenforcing ribs, were made and held in place by steel rods passing through the pipe and both disks. The inside faces of these disks were perfectly smooth, plane surfaces, as shown on Pl. III.

To prevent leakage between the disk and the end of the pipe a ring of round rubber tire, 1¼ inches in diameter, was placed between the disk

and the shell of the pipe, and when the rods were tightened by the nuts at each end this gasket was flattened on the end of the pipe and formed a most effectual and tight joint under low pressures. It was found, however, that under high pressures the gasket was stretched at the joint, which was not vulcanized, and forced toward the outside of the pipe and caused leakage. To remedy this a ring of ½- by 1-inch bar steel was placed around the gasket and between the disk and the end of the pipe, and no further trouble arose here.

In Pl. II, *B*, one of the disks is clearly shown on the end of pipe No. 2. The pipe is all ready for testing. The small pipe to the left of the gage is designed to allow air to escape when the pipe is being filled, each pipe being raised at one end so that the air can be expelled before pressure is applied.

The connection to the right of and below the gage is for filling the pipe from the city water pipe in the yard. The pipe in the lower left-hand corner is connected with a pump for raising pressure above city water pressures. The large connection in the lowest part of the disk is for emptying the pipe. The eye in the upper part of the disk, to the left of the center, is for the purpose of holding the disk when the rods are being adjusted. Each disk weighs about 1,500 pounds, and was raised to its place by a differential pulley hung from the light frame shown at the farther end of the pipe.

The disk at the farther end of the pipe is exactly similar and symmetrical with the one shown, but has no pipe connections, as they are not needed.

Pl. IV, *A*, shows another pipe under test with pump and hose complete.

Pl. IV, *B*, shows the method of raising the pipes at one end after they had been rolled to one side.

Each pipe weighed about 10 tons, and had to be raised with jack-screws and a sling of manila rope, as it was found impracticable to raise it by wedging, the material of the pipe being easily injured at the ends, where it was needed in perfect condition to allow a tight joint between disk and pipe.

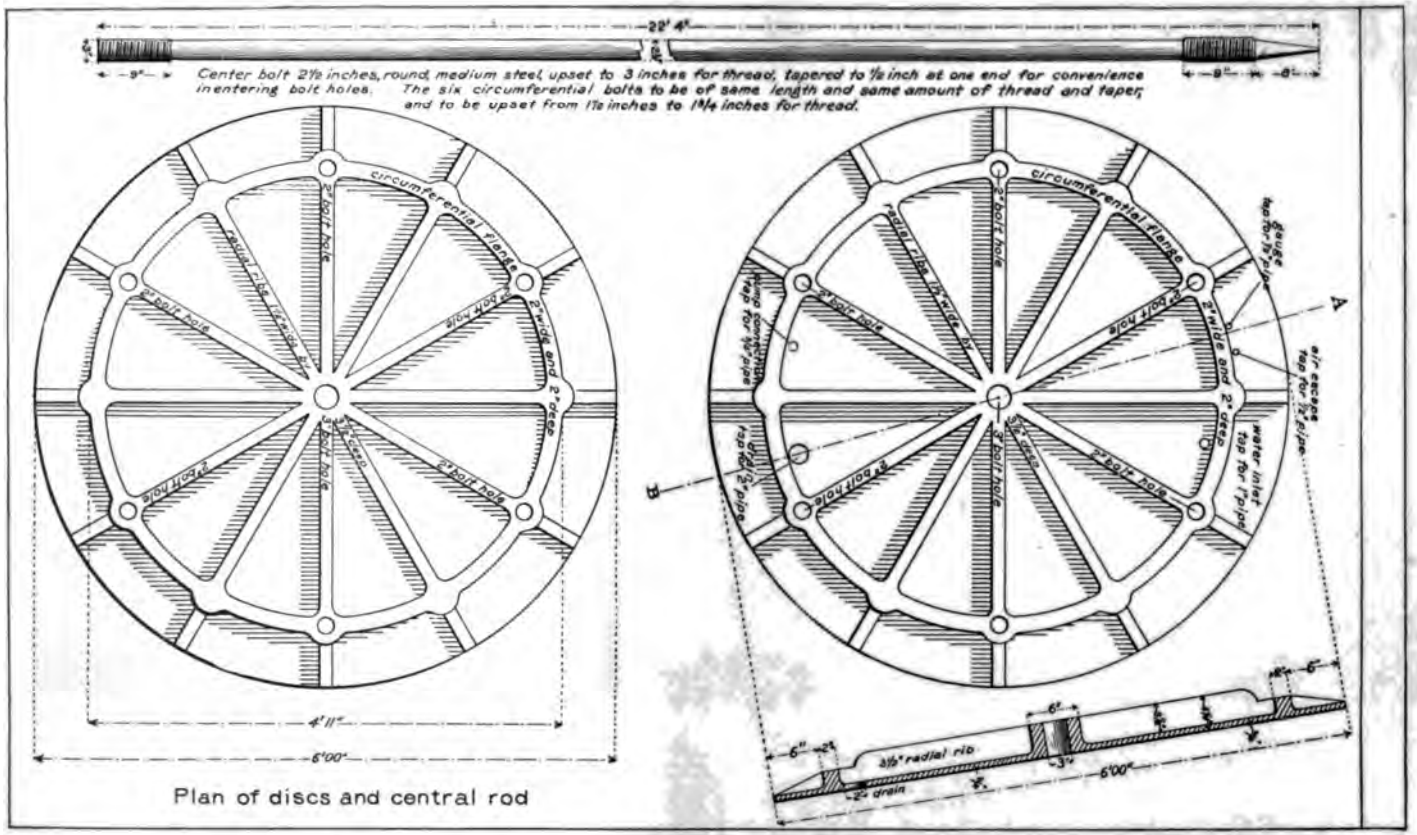
TESTS.

The pipes lay in a position nearly east and west, the east ends being shown in the front of all photographs.

PIPE NO. 1.

PLASTER LININGS.

On October 19, 1903, this pipe was covered on the inside with one-half inch of plaster. Four plasters were used, the section covered by each plaster being 5 feet in length.



Plan of discs and central rod

Plaster No. 1 was composed of 1 part cement to 1 part fine sand.

Plaster No. 2 was composed of 1 part cement and 1 part fine sand, mixed with alum and soap mixture—alum, 1 per cent by weight of cement and sand; soap, 1 per cent by weight of water.

Plaster No. 3 was composed of 1 part lime, 2 parts cement, and 6 parts sand.

Plaster No. 4 was composed of ¼ part lime, 1 part cement, and 3¾ parts fine sand.

The plasters were kept well wet for several days after completion, and the test of the pipe was not made until February 26, 1904.

Pipe No. 1, Test 1.

The results of the first test of pipe No. 1 are shown in the following table:

Test 1 of pipe No. 1.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Feb. 26	9.08 a. m.	0	Water turned into pipe.
	12.58 p. m.	0	Pipe full.
	12.60 p. m.	15	Leakage began. Especially strong along a longitudinal seam, hereinafter designated as a "tamping seam," caused by necessary delay in adjustment of form.
	Later.	23	Gage stationary; inflow counterbalanced by leakage. South side (most exposed to sun) is porous and leaks badly. No leakage from top section, which was tamped without form.
	1.30 p. m.	20	
	3.00 p. m.	.....	Leakage on north side decreased fully 20 per cent.
	3.20 p. m.	24.5	
	4.45 p. m.	25.5	Decrease of 75 per cent in entire leakage.
	5.00 p. m.	.....	No leakage in top section. Pressure turned off for night.
Feb. 27	8.00 a. m.	25	Only 20 per cent of initial leakage persists.
	2.00 p. m.	.....	Top section shows little moisture only. North side, leakage almost ceased. South side, leakage decreasing; laitance appearing.
			Pressure continued all night.
Feb. 28	11.30 p. m.	15	Gasket blown out causing small leak.
			Pipe leaking on south side only.
			Pressure continued all night.
Feb. 29	8.00 a. m.	14.5	Not leaking appreciably except at gasket. Laitance oozed out, nearly stopping holes in pipe.
	9.00 a. m.	.....	Pipe emptied to repair gasket.

Of the four plasters applied to the inside of the pipe, as described on page 19, it was found that No. 4 allowed the smallest amount of leakage, while Nos. 1, 2, and 3, in order, rank next in effectiveness.

When pipe No. 1 was being constructed the sections next to the top on both sides were made of dry mixture, by order of Mr. W. H. Sanders, as the watery cement was oozing from the boards at the bottom. It is remarkable that these two sections of 18 inches each show greater leakage and more gravel uncovered with mortar at the outside surface of pipe than the other sections. The other layers were put in very wet and the boards of the forms were coated with a layer of almost pure cement.

When the water was drained off and the disks were removed, an examination of the inside of the pipe revealed a hair crack the full length of the pipe on the south side, at the junction of the last section with the top section. This crack crossed all the mortars and was evidently due to a slight yielding of the concrete before the strain could be taken up by the steel armor.

This pipe was made with gravel of different sizes, with the idea that it might be less porous than a pipe with gravel of a more uniform size. It must be admitted, however, that the filling up of the interstices of the coarser material by the finer, which appears so plausible in theory, is most difficult to accomplish in practice.

The crack developed in the pipe shows that some lining or plaster of an elastic as well as of an impermeable nature must be found before these pipes can be placed under much pressure. A great many of the experiments have this end in view.

No arrangements had been made up to this time to measure the amount of the leakage from the pipes. It is evident that although a pipe might eventually dry up to such an extent under pressure as to reduce the leakage to an inappreciable amount, it might leak sufficiently before drying up to endanger its foundation, and cause the destruction of the pipe piecemeal. This would depend to some extent upon local conditions and the nature of the material on which the pipe rested. It will be seen from this experiment that the leakage is very much reduced by time, but it is doubtful whether this fact could often be used to advantage in practice, for the above-mentioned reasons.

The practically constant pressure of the city main was found to be much more advantageous for working on these pipes than the pressure developed by pumping. A quantity of laitance appeared on the outside surface of all pipes a few hours after they were put under pressure, and more or less matter composed of lime particles was con-

A. PIPE UNDER TEST.

B. METHOD OF RAISING END OF PIPE.

tantly exuding from them. Experience has shown that this material gradually fills up the pores and renders the pipe more impervious. A high pressure applied suddenly, as in pumping, would tend to force this matter rapidly through the pores and a great deal of it would be lost; whereas a slow, steady pressure would naturally permit a greater deposit. As a matter of fact few of the pipes or mortars were sufficiently impermeable to call for the aid of the pump in testing, as the city pressure varied between 37 and 42 pounds to the square inch, and this was as much as most of the pipes would stand without leaking so much as to endanger their foundations.

PIPE NO. 1, TEST 2.

As stated above (p. 18), this pipe was coated inside with four plasters in 5-foot sections. It received an additional coating of two coats of P. & B. waterproof paint on the east half and two coats of Sylvester wash on the west half. On March 11, 1904, at 7.45 a. m., city water was turned on and gage immediately rose to 35 pounds. Leakage became free for the south side of the pipe, and was about twice as much as on the north side, while the portions covered by the P. & B. paint did not leak one-half as much as those covered by the Sylvester wash. This was very evident on top, which, in the section covered by P. & B. paint, showed barely a trace of moisture, but seven-eighths of the surface of the section covered by plaster No. 4 was moist. This was the plaster which showed the slowest percolation under test No. 1.

At 9 a. m. the gage registered 36 pounds and the leakage was 2¾ gallons per minute.

At 10 a. m. gage registered 37 pounds. Leakage about the same.

At 3 p. m. the pressure was reduced to 30 pounds and the leakage amounted to 2¼ gallons per minute.

PIPE NO. 2.

PLASTER LININGS.

This pipe was covered on the inside October 20, 1903, with a half-inch coat of two different plasters, the section covered by each plaster being 10 feet in length.

Plaster No. 1 at the east end was composed of 1 part cement and 3 parts sand, loose measurement.

Plaster No. 2 at the west end was composed of 1 part cement, one-half part lime, and 4½ parts sand, loose measurement.

PIPE NO. 2, TEST 1.

The results of the first test of pipe No. 2 are as follows:

Test 1 of pipe No. 2.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 1	9.00 a. m.	0	Water turned into pipe.
	11.30 a. m.	0	Leakage from 2 pin holes, north side, one-third way up.
	11.45 a. m.	0	Leakage from 3 more pin holes on south side, east section, along line of "tamping seam."
	12.00 m.	0	Leakage from 5 more pin holes on south side at a "tamping seam;" 4 in east section, one in west section.
	1.30 p. m.	.....	Pipe full and pressure developed.
	1.31 p. m.	13	Strong leakage commenced.
	1.32 p. m.	25	Gage stationary, leakage counterbalances inflow.
	2.00 p. m.	25	Leakage on south (sunny) side twice as great as on north. Practically no leakage on top section.
	2.45 p. m.	29	Leakage decreased generally.
	4.00 p. m.	31	Leakage still decreasing.
	4.15 p. m.	31	
	4.30 p. m.	31.5	Laitance and lime particles exuding freely.
	5.00 p. m.	31.75	Leakage water shows lime.
	8.05 p. m.	35	Entire top section sweating freely. Lime forming rapidly where leakage is greatest.
	8.25 p. m.	35	Pressure continued all night.
Mar. 2	7.40 a. m.	.....	Gasket on west end blown out. Pipe empty.

The city pressure in the mains is greatest early in the morning, when the draft on the reservoir is least and the inflow has raised the water to its maximum level for that day. It is presumed that when this pressure came on the pipe the friction between the disk and the rubber was not great enough to hold the gasket in place and it blew out at the joint. As the pressure had remained for about 20 minutes at 35 pounds, it is presumed that the leakage had continued to decrease and the pressure to rise accordingly until this accident happened some time during the night. To prevent a recurrence of this trouble a welded steel ring of section one-half by 1 inch and large enough to fit around the gasket when under pressure was made for each end, and these were placed in position and the heads were screwed up a quarter of an inch tighter than before.

PIPE NO. 2, TEST 2.

ie results of the second test of pipe No. 2 are as follows:

Test 2 of pipe No. 2.

te.	Hour.	Pressure.	Observations.
		Pounds.	
2	5.00 p. m.	0	Water turned into pipe.
	8.10 p. m.	.....	Pipe three-fourths full. Slight sweating on lower part of north side of east half and on south side of west half. Gaskets and rod washers tight.
	9.40 p. m.	.....	Pipe full and air vent closed.
	9.43 p. m.	30	
	9.45 p. m.	32.5	Leakage in streaks on both sides, most on south, none on top.
	9.55 p. m.	33.5	Leakage worst on south side but less than in test 1, laitance and lime particles having closed some of the pores of the pipe. Water spurts to a distance of 4 feet from large pin hole near top on west end.
	10.10 p. m.	34	Pressure shut off for night.
3	7.40 a. m.	.....	Pipe sweating and dripping at numerous points, mostly near east end. Water turned into pipe.
	7.48 a. m.	.....	Pipe full. See discussion below on amount of leakage.
	7.49 a. m.	25	
	8.00 a. m.	32	Leakage free on south side. At east end on south side there is a junction of the bottom and next section above. Water still spouts 4 feet from large pin hole.
	8.55 a. m.	32.75	
	10.00 a. m.	34.5	
	11.00 a. m.	35	
	11.15 a. m.	35	
	11.15 a. m. to 4.45 p. m.	35 to 36.5	Leakage measured on weir shows about 3 gallons per minute, or five times as much as when pipe is full but under no pressure.
	4.45 p. m.	15	Pressure reduced to 15 pounds for the night.
	5.00 p. m.	15	Leakage measured on weir one-half gallon per minute, showing that pores had filled up somewhat during day, as it had leaked 0.6 per minute during previous night, when under no pressure.
4	7.45 a. m.	19	Increase in pressure due to increase in city mains. Pipe sweating freely, 0.36 gallon per minute. Full city pressure turned on.
	7.46 a. m.	36	
	7.49 a. m.	35	
	8.30 a. m.	35	Weir indicated leakage of 2.25 gallons per minute, a sensible decrease from day previous.
	9.30 a. m.	36.5	One-inch tin weir substituted for 2-inch weir. Shows leakage of 2 gallons per minute. Greater part of leakage at one spot near bottom of pipe at east end.
	10.15 a. m.	.....	Pipe emptied and examined.

It will be noted from the above table that on March 3 at 7.40 a. m. the water was turned into the pipe and in 8 minutes it was full, indicating that the pipe had leaked when not under pressure during the night a quantity equal to the run of the faucet for 8 minutes. Pipe No. 1 required 3 hours and 50 minutes to fill, and No. 2 required 4½ hours; the content of each pipe with heads screwed tight is about 395 cubic feet. Taking the mean time of filling the pipes as 250 minutes, the flow from the faucet would be 1.58 cubic feet per minute, and this multiplied by 8 equals 12.64 cubic feet, which represents the leakage during the night when no pressure was left on. This leakage, equivalent to 92½ gallons, occurred in 9½ hours of the night. This means a leakage from the pipe when not under pressure of 10 gallons an hour or 0.6 of a gallon per minute.

Provision was then made for measuring the leakage from the pipe when under pressure by making drains beneath it for collecting all the leakage water and leading it to a small tin weir 2 inches long.

The sand-cement plaster lining contained a perfect network of hair cracks, while the lime-cement plaster showed hardly any. The greatest leakage appeared to be in the east section of the pipe, which had been plastered with the sand-cement mixture.

Both sides of the pipe were thickly covered with laitance and lime deposits, but very little of either of these appeared on the top of the pipe.

PIPE NO. 2, TEST 3.

This pipe was originally treated with two kinds of cement mortar, and when tested the first time showed a leakage of 3 gallons per minute under a pressure of 37 pounds per square inch. It was then washed on the inside of the east half with two coats of pure cement wash, and on the west half with two coats of Sylvester wash.

Test 3 of pipe No. 2.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 17	7.30 a. m.	32	No leakage below this pressure.
		35	Leakage 1 gallon per minute.
			Top section of the pipe shows moisture only in spots over about one-third of its area.
	9.00 a. m.	36½	Leakage 1 gallon per minute.
	10.00 a. m.	37	Do.
	1.00 p. m.	39	Do.
	3.00 p. m.	38	Do.
			Considerable laitance formed on upper half of pipe. Leakage more of a general sweat and less flowing streams.

Test 3 of pipe No. 2—Continued.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 17	5.00 p. m.	38	Leakage about 1 gallon per minute. Full city pressure left on all night.
Mar. 18	8.00 a. m.	35	Leakage 2½ gallons per minute; caused probably by opening of new pin holes or seams as result of extra-heavy pressure on city mains developed during the night.
	8.30 a. m.	0	Pipe allowed to remain full all day and during night
Mar. 19	8.00 a. m.	22	Full city pressure turned on. No leakage, except at one spot in bottom; apparently a serious imperfection in pipe.
	8.15 a. m.	24	Seepage on surface of pipe.
	9.00 a. m.	35	Sweat is more general, but not as much as on Mar. 17.

PIPE NO. 2, TEST 4.

Pipe No. 2 received a coat of Richards plaster, which was placed over the plaster already on from test 2, and a half sack of clay was deposited in the pipe before the heads were attached. On April 28, 1904, this pipe was filled at 2 p. m. Pressure, however, was not applied till 2.30 p. m., so that Mr. Richards might be present at the test. There was absolutely no moisture visible on the outside of the pipe up to this time. This was not the case in previous tests. When the pressure was applied, the gage rose steadily until it reached 32 pounds and fluctuated between 32 and 34 pounds for half an hour before any leak was seen except near the bottom on the west end, where there was supposed to be a flaw in the pipe. In an hour there was a strong sweat at several places on the outside of the pipe, but not sufficient to allow any water to flow away. The weir showed a leakage of nearly 2 gallons per minute, nearly all of which came from the flaw. At 5 p. m. there was a trifle more sweat on the pipe, but the ground under and around the pipe remained dry, except at the west end, where the flaw was located. The pressure was now reduced and the pipe was left under a low pressure all night.

In the morning (April 29) the pipe was very sweaty under a pressure of 12 pounds, although there were several dry spots. The ground was somewhat moist in places, but was not soaked. The full pressure was now turned on, and the gage rose to 35 pounds. There was no visible leakage, the surface of the pipe drying off rapidly under the influence of the sun's rays. The water in the pipe was stirred up at intervals to keep the clay moving. The pipe remained under this pressure all day without any apparent change. The water which escaped through the flaw was colored with clay.

The pump was applied in the afternoon and the pressure was raised to 40 pounds. The leakage through the flaw was so great, however, that it was determined to remove the heads and repair the flaw. This was done, and on May 2, 1904, the pipe was overhauled and a distinct crack was found in the plaster over the flaw in the pipe. The plaster was chipped off for about 2 feet square, and the imperfect part of the pipe itself was chiseled out to a depth of 2 inches. This was filled with good cement mortar and allowed to set thoroughly. In cutting into the crack or flaw it was found partly filled with clay.

On May 5 a coat of Richards plaster was placed on that part of the pipe that had been repaired, and on May 10 the pipe was filled at noon. As soon as the pressure was turned on the gage rose slowly to 39 pounds, and fluctuated between 38 and 40 pounds till 12.30 p. m., when moist spots began to show on the outside of the pipe, mostly on the south side.

At 1 p. m., the pressure remaining the same, the total amount of moist surface on the south side did not exceed 1 square yard, while the amount on the north side did not exceed 1½ square feet.

At 1.30 p. m. the sweating had spread a little more, the pressure remaining the same. A little leakage around the gasket at the west end was probably caused by the plaster near the flaw not being thoroughly set. This leakage through the gasket amounted to a little less than one-tenth gallon per minute. The pump was now attached and the pressure was raised to 53 pounds, when the pipe commenced to sweat considerably. The pressure was kept up to this point for fifteen minutes, the sweating increased somewhat, and water began dripping in places along the south side.

At 2 p. m. the pressure was raised to 63 pounds and held there by pumping for two minutes. This developed a very strong sweat and a small leak near the top on the north side. The dripping increased to such an extent as to cause water to gather in the little drains at the sides of the pipe. The pressure was now lowered to 55 pounds and held there till 2.45 p. m., when the leakage amounted to half a gallon per minute, fully one-fifth of which came through the gasket. The pressure was maintained at from 53 to 56 pounds until 3.45 p. m., and the clay was kept in motion all the time, the weir showing an increase under this constant pressure.

At 4 p. m. the pressure was allowed to fall to that of the city mains, and the gage registered 37 pounds.

At 4.30 p. m. the weir showed a leakage of one-tenth gallon only, which came entirely from one leak at gasket, the drip from the sweaty sides of the pipe not being sufficient to make the water flow to the weir. The pipe was left under pressure all night.

On May 11, at 8 a. m. the gage registered 38 pounds, the weir did

not show any flow, and there was scarcely any drip from the sides of the pipe. The pipe was allowed to stand under city pressure and the clay stirred up occasionally until 3 p. m., when the pump was applied and the pressure raised to 55 pounds. At this pressure the weir showed a leakage of four-tenths of a gallon per minute. The pressure was then raised to 62 pounds and held there for a few minutes, and the leakage shown by the weir was three-fourths of a gallon per minute. When the pressure was reduced to 55 pounds the leakage fell to four-tenths of a gallon per minute.

The pipe remained under pressure all night, and at 8 a. m. on May 12 the gage read 39 pounds and there was no drip from the pipe. The surface on the outside of the pipe, however, was sweaty, but this moisture disappeared to a great extent under the influence of the sun. The pipe remained under city pressure all day (37–39 pounds) and the clay was kept stirred up occasionally, but there was no apparent change in the condition of the pipe, so this experiment was concluded, and the heads were moved to No. 3. This was a very satisfactory test.

When this pipe was thoroughly washed inside to remove the clay, it was found that the plaster was still soft. This might account for the high pressure which this pipe stood, as a harder mortar might have cracked and caused greater leakage. A plaster which would remain soft and plastic for a long time might possibly afford a solution of the problem.

It will be observed that in these tests the amount of leakage varies considerably with the same pressure on different pipes. It was thought at first that the pressure and leakage should be proportional, but a little consideration will show that this could not be so.

It requires a greater pressure to force a given quantity of water through twelve small holes than it does to force the same quantity of water through one hole as large as all the small ones together, in the same time. If, therefore, the quantity of water which leaks through a pipe with only one opening is the same as that which passes through numerous small holes in another pipe in the same time, it is evident that the pressure on the pipe with small holes must be greater than that on the pipe with one large hole.

We may conclude then, that the pressure on a sweaty pipe will be greater than on a pipe with a few well-defined leaks, where the leakage is the same in both, in the same time, and that, with the same pressure, the leakage may vary with the number and character of the openings through which it takes place. This shows the great importance of careful workmanship on pipes of this kind. Unfortunately this class of work is most frequently done with unskilled labor, so that the practical difficulties in the way of producing a waterproof pipe, for a reasonable price, are thereby much increased.

PIPE NO. 3.

PIPE NO. 3, TEST 1.

This pipe, as may be seen from its composition (p. 14), was made with the idea of testing a pipe constructed of waterproof material, and no coat of plaster was placed upon the inside.

Test 1 of Pipe No. 3.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 7	4.00 p.m.	0	Water turned into pipe.
	5.00 p.m.	0	Leakage commenced on south construction side of pipe; in general, much less leakage than in pipes Nos. 1, 2, and 4, as filling proceeds.
	7.45 p.m.	0	Leakages from pinholes in tamping seams at bottom are more numerous than elsewhere.
	9.15 p.m.	4	Pipe full and pressure turned on. Many pin holes develop. Leakage exceeds 9 gallons per minute. Pipe most impervious of any yet tested. Pressure turned down for night.
Mar. 8	9.30 a.m.	4	Leakage 9 gallons per minute.
	10.00 a.m.	5	Leakage about the same.
	10.30 a.m.	6½	Leakage 8 gallons per minute.
	10.45 a.m.	7	Do.
	11.00 a.m.	8	Do.
	4.00 p.m.	11½	Leakage 6 gallons per minute.

In the first test it was left in its rough state inside, just as it came from the forms, without any mortar, and the highest pressure that could be obtained on it was 12 pounds to the square inch, with a leakage of 5 gallons per minute. As the leakage was already sufficient to show that it would be unwise to build a pipe under such conditions in practice, it was determined to conclude this experiment, and the water was turned off and the pipe allowed to drain.

It was decided to give this pipe a coating of the different kinds of plaster and make another test on it, which is described below. It is very evident from the experiments that although the leakage decreases rapidly with time, some impermeable mixture in the shape of plaster must be applied to the inside of these pipes to prevent the immense leakage which would otherwise take place when the water is turned into the pipe. Such a plaster would allow a more gradual penetration of the material of the pipe by the water, and probably afford better conditions for filling the pores of the concrete with the compounds of lime which tend to close them, and render the concrete impervious.

PIPE NO. 3, TEST 2.

The original composition of the pipe was 1 part cement, 2 parts sand, and 3.2 parts gravel (half-inch mesh), mixed with water impregnated with soap and alum.

The pipe now was coated inside on the east half with a mortar half an inch thick, composed of 1 part of lime paste, 1 part of iron filings, 2 parts of cement, and 6 parts of sand, all mixed with water having iron filings and sal ammoniac in the proportion of 70 pounds of iron filings and 12 ounces of sal ammoniac to 42 gallons of water. This mortar was first tried without lime, but it was found very difficult to make it adhere to the pipe. The lime was added to overcome the difficulty, and was quite successful for the purpose. The west half of this pipe was coated with half an inch of mortar, composed of 1 part of fine clay and 1 part of cement. This mortar checked badly in setting, but it was allowed to dry under the same conditions as the other mortar, the checks being permitted to remain as they developed, in order to determine how it would act under pressure. The iron mortar was finished on March 9, the clay mortar on March 10, and the pressure was turned on the pipe at 4 p. m. March 14. The pressure ran up rapidly to 20 pounds per square inch without any leakage. Some small seams and pin holes then commenced to leak, and kept increasing until the pressure was up to 35 pounds, when the leakage amounted to 2½ gallons per minute. Three-fourths of this leakage was in the clay end of the pipe, and the iron mortar was evidently by far the more impermeable. From 4 to 5 p. m. there was a very evident filling up of the leaky spots, all the pin-hole jets decreasing until they were tiny leaks. The pressure was left on all night, and on the morning of March 15, at 8.30, the gage read 38 pounds, and the leakage was a little less than 1 gallon per minute.

With a pressure of 35 pounds the leakage through the iron mortar is not over one-tenth of that through the clay, and is so small as to be of no consequence in practice. The result of this experiment shows that with a pipe of Sylvester wash composition, and a mortar of iron filings, sal ammoniac, cement, lime, and sand, a head of 80 feet would be possible. Just how the sal ammoniac would act on the steel armor embedded in concrete it is impossible to state, and the condition of the armor when the pipe was broken is noted on p. 58.

One peculiar circumstance connected with this pipe was that although the pressure in the morning was 38 pounds with a leakage of less than a gallon per minute, when the pressure was down to 35 pounds, owing, it is supposed, to the variations in the quantity of water drawn from the city pipes, water commenced to spurt in high jets from the pin holes, which had shown very little leakage at 38 pounds. These jets were all in the clay portion of the pipe. A possible explanation of this peculiar action is that the pin holes had been stopped up by small,

loose particles of clay on the inside surface of the mortar. As soon as the pressure was relieved by a sudden draft on the city water pipes these particles may have been so far removed to one side of the pin hole as to allow the water to spout again. The pump was turned on to this pipe at 9 a. m., and the pressure forced up to 42 pounds. This started a few small jets through the iron mortar and increased those already found in the clay mortar to such an extent as would prevent the use of that part of the pipe under that pressure in practice. When the heads were removed it was found that the mortars had cracked for the full length of the pipe in four different places at tamping seams, and all of the pin-hole leaks through the iron mortar were traced to these seams.

It was noticeable in this test that considerably more laitance appeared on the surface of the pipe at the east end than on that of the west end, although the leakage was very much less on the former section.

Thirty-eight pounds seems to be about the limit of pressure for this pipe and mortar. This is equivalent to a head of 87 feet, but considering the many imperfections of work in actual practice, it would not be safe to count on over 70 feet of head on such a pipe, and then only after the most rigid inspection and supervision of the construction of the pipe.

It is evident from this experiment that as soon as the pressure is sufficient to stretch the steel beyond the tensile strength of the concrete the yielding of the concrete will allow the weakest seam to open.

When pumping, the pressure tending to burst the pipe was, for 1 inch in length of pipe,

$$42 \times 30 \text{ (radius in inches)} = 1{,}260 \text{ pounds,}$$

and the area of section of concrete resisting this pressure was 6 square inches, so that the actual strain on the concrete alone amounted to $\frac{1260}{6} = 210$ pounds per square inch. The steel rods are three-fourths inch in diameter and are set $3\frac{3}{8}$ inches from center to center, so that if the pressure is taken up by the steel alone it would amount to

$$\frac{1260 \times 3\frac{3}{8}}{0.44} = 9{,}664 \text{ pounds per square inch,}$$

and although this is below the elastic limit of the steel this strain would cause the steel to stretch enough to crack the concrete, which, of course, would yield first at the weakest place, probably a seam.

Practically, it is very difficult, if not impossible, to make concrete pipes of large diameter without seams, either longitudinal or transverse, and to overcome this defect it would be necessary to have an elastic as well as an impermeable quality in the plaster. Efforts will be made in future tests to find such a plaster for lining.

PIPE NO. 3, TEST 3.

the second test of this pipe, described above, two different kinds ortar were used—iron mortar on the east half and clay mortar on half. As the clay mortar did not give satisfactory results it was led off and in its place was substituted a plaster composed of 1 of Ideal cement, 1 part screened sand, and one-fourth part lime r, all moistened with iron and sal ammoniac water. The east half allowed to remain as it was in test No. 2. The entire inside of was coated with a wash of cement mixed with "iron" water.

Test 3 of pipe No. 3.

e.	Hour.	Pressure.	Observations.
		Pounds.	
23	2.55 p. m.	25	Pressure turned on. Number of pin holes north side near top spouting.
		30	Few small leaks on south side near top.
	3.30 p. m.	35	Leakage strong along two of the cracks which were visible on inside of the pipe after second test.
	4.00 p. m.	39.25	Leakage 1.75 gallons per minute. Leakage on south side diminished. No pin holes spouting. North side, 9 or 10 pin holes spouting. Ninety per cent of all leakage occurs here.
	4.30 p. m.	39.25	Same leakage as above.
	5.00 p. m.	20	Pressure reduced for the night to allow cracks to close up. Leakage 0.75 gallon per minute with strong sweat at cracks and no pin holes.
	8.15 p. m.	30	Leakage 0.75 gallon per minute. Strong sweat. No pin holes.
24	7.30 a. m.	36	Leakage 0.25 gallon per minute.
	7.30 a. m.	38	Full city pressure. No perceptible change in appearance of pipe.
	8.00 a. m.	39.5	Leakage 0.25 gallon per minute.
	9.00 a. m.	40	A few pin holes commenced to spout. Pressure then turned down to 32 pounds, and spouting ceased.
			This pressure continued to ascertain if leaking seam will close or cease to leak at higher pressure.
	12.00 m.	32	Pipe drying fast. Weir shows leakage less than 0.1 gallon per minute.
	2.00 p. m.	32	Pipe much dryer.
	4.30 p. m.	35	Leakage so small as to be barely recorded. Pipe dry over half this surface.
25	7.30 a. m.	34	Only sweat in parts of crack. Weir shows no perceptible leakage. Full city pressure turned on.
	7.45 a. m.	40	No strong leaks until 8.15.
	8.15 a. m.	40	Leakage 0.3 gallon per minute. Pump started and pressure raised to 45 pounds. All pin holes spout freely.
		48.5	Cracks leaked so much that pump can not overtake leakage.

When the heads were removed from this pipe the two old cracks from test 5 were seen plainly developed in the plaster, although one did not run through the full length of the pipe. There were also three small new cracks visible. This was certainly the most satisfactory of all the tests so far. It must be borne in mind that a pipe in actual practice would not be subject to much fluctuation in pressure, and as long as the pipe did not leak materially under the pressure due to the maximum level of water in the canal, it would probably get more impermeable with age. The ends of the pipe being always open it could not be subjected to very severe water hammer if proper provision was made for removing air.

Pipe No. 3, Test 4.

When this test was made the pipe was in the same state as after the third test, except that the plaster was repaired. Before the heads were put on this pipe there was placed inside of it 100 pounds of clay and 2 pounds of wood ashes, the object of this test being to determine the efficiency of clay and ashes as a means of stopping leakage in a concrete pipe.

On April 19, 1904, at 3.45 p. m., this pipe was filled and the pressure rose to 25 pounds before any noticeable leak occurred. When the pressure reached 30 pounds leakage became greater, and water spouted very freely along the seams that had been chiseled out and filled with mortar on the inside. The clay and ashes were kept well stirred up inside and the water which came through the leaky places was very muddy. The pressure was gradually increased to 32 pounds; the leakage was 4½ gallons per minute. This pressure was kept on during the rest of the day, the clay being stirred constantly. At 5 p. m. the pressure was reduced for the night. On April 20, 1904, at 8 a. m., full pressure was again turned on and clay stirred up. The pressure rose to 34 pounds and the leakage amounted to 3¾ gallons per minute. By noon the pressure had increased to 35 pounds, but the clay seemed to blow through the cracks and the pipe was leaking so much that it was decided to discontinue the experiment.

Pipe No. 3, Test 5.

The pipe was thoroughly washed inside to remove all the clay which remained after test 4. This left the pipe with one-half inch of two different kinds of plaster on the inside, as described in tests 3 and 4.

On April 26 an additional plaster of 1 part of cement to 1½ parts of sand was applied and troweled down to a smooth surface. This plaster was kept well wet till seasoned, and on May 14 the pipe was filled, a sack of clay having first been deposited inside.

Test 5 of Pipe No. 3.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
ay 14	10.30 a. m.	32	Two large pin holes near top on east end of north side; 1 small pin hole at west end.
	11.00 a. m.	.....	Strong sweat spots on north side. Small pin holes stopped spouting.
	12.00 m.	37	General sweat on pipe. Leakage 0.75 gallon per minute. Clay stirred constantly, and pressure allowed to remain all the afternoon, fluctuating between 35 and 40 pounds.
	5.00 p. m.	.....	Weir indicates leakage of a little more than one-half gallon per minute.
ay 16	8.00 a. m.	38	General sweat; 2 large pin holes, leaking freely. Total leakage, one-half gallon per minute.
	5.00 p. m.	36	Leakage about same as in the morning.
ay 17	8.00 a. m.	39	Leakage 0.4 gallon per minute. Considerable laitance has formed on outside of the pipe. As finger is run along full length of pipe sweat seems to break and does not show any flow except on north side, where several leaks are found. At place of leakage thick coat of iron oxide deposited on outside of pipe. Clay constantly stirred during forenoon.
	12.00 m.	39	Leakage 0.35 gallon per minute.
	2.30 p. m.	56	Pump attached. Pressure maintained for 25 minutes. Leakage of 1 gallon per minute. Leakage along upper seam on north side. Strong sweat on south side
	2.55 p. m.	62	Pressure raised by fast pumping and held for 12 minutes. Leakage 2 gallons per minute. Ten per cent from bolt holes and gaskets.
	3.00 p. m.	.....	Pressure allowed to fall to that in city mains and maintained there for remainder of day.
	3.30 p. m.	36	Leakage 0.75 gallon per minute. This would indicate that the pores of the pipe had been opened by great pressure.
	5.15 p. m.	38	Slight reduction in leakage. Pipe is left under city pressure all night.
ay 18	8.00 a. m.	39	Leakage 0.5 gallon per minute. Pores apparently closing up. Pressure kept on all day; clay agitated.
	5.00 p. m.	38	Slightly reduced leakage. Pressure left on all night.
ay 19	8.00 a. m.	37	Leakage 0.35 gallon per minute. Pipe under city pressure all day.
	5.00 p. m.	38	Leakage 0.35 gallon per minute. Pipe under pressure all night.
ay 20	.....	37	Leakage 0.35 gallon per minute. Considerable laitance and lime on the surface. No leakage, except at pin holes, where oxide of iron is getting harder. Pipe under pressure all night and all next day.

Test 5 of Pipe No. 3—Continued.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
May 20	5.00 p. m.	.....	Pipe quite dry. Leakage 0.3 gallon per minute. Pipe left under pressure until May 23, when pressure was reduced to zero.
May 25	.....	38	Leakage 0.25 gallon per minute. Pipe left under pressure for night.
May 26	.....	38	Leakage 0.1 gallon per minute. Pressure continued.
May 27	.....	38–40	Same leakage; pressure released at noon.
	5.00 p. m.	.....	Pressure again applied and continued all night.
May 28	.....	39	Pipe quite dry. Leakage less than 0.1 gallon per minute. Pressure continued.
May 29	.....	39	Conditions same as day previous. Pressure now turned off. Pipe allowed to remain full of water until June 2.
June 2	.....	60	Pressure raised by pumping. Increased for a short time to 65 pounds, when new pin holes blew out on south side. Pressure allowed to fall to 38 pounds and allowed to remain there until June 9.

This pipe was left under city pressure from 5 p. m., May 14, to 8 a. m., May 16. Many engineers and practical pipe makers assert that time is an important element in closing the pores of a cement pipe. This was considered an excellent opportunity for this test, as the workmen were employed in the yard making another pipe of the same diameter and thickness, but in sections of 5 feet each.

June 9, 1904, when the leakage had been reduced so that it could no longer be measured through a weir 1 inch wide, the only leaks visible on the surface were from the two pin holes on top, and the leaks from them had been very much reduced in the last few days. This pipe had now been practically under city pressure for about three weeks, and the leakage had decreased from three-fourths gallon per minute to less than one-tenth gallon per minute.

This reduction of leakage might be due to the filling up of the pores of the pipe in this case with clay, lime deposits, laitance, or oxide of iron, or partly with one or more of these substances.

The fact that oxide of iron formed rapidly on outside of the pipe only at the pin holes does not necessarily prove that the sal ammoniac might permeate the concrete and attack the steel rods, but naturally leads to grave suspicion that it does so. An examination of the steel rods where the pipes are broken up will show what has happened.

Just what influence the clay may have had in this case it is difficult to say, but another experiment will show what clay can do on an unplastered concrete pipe.

PIPE NO. 4.

PIPE NO. 4, TEST 1.

Pipe No. 4 was constructed September 12, 1903. No plastering was done on this pipe. During the time the experiments were being made on pipes Nos. 1 and 2, from February 26 to March 4, 1904, this pipe was coated inside on its east half with two coats of P. & B. waterproof paint No. 1, and its west half with three coats of soap and alum mixture, commonly called "Sylvester wash." This was applied precisely as recommended in Trautwine's Pocket Book, p. 672. It was assumed from the results of experiments on pipes Nos. 1 and 2 that it would be useless to attempt a test of a pipe without some waterproof plaster or wash on the inside. The Sylvester wash being so much used for waterproofing was thought to be a good wash with which to make the first test, and as an elastic coating of some kind was deemed important the P. & B. paint was selected.

Test 1 of pipe No. 4.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 4	4.30 p. m.	0	Water turned into pipe.
	5.00 p. m.	0	2 small sweat spots on P. & B. section; strong drip on Sylvester wash section.
	8.40 p. m.	0	Pipe seven-eighths full. Only slight seepage in lower half.
	9.25 p. m.	0	Pipe full. Leaks develop freely in both sections. Gage would not record; therefore removed for repairs, and light pressure left on pipe all night.
Mar. 5	8.00 a. m.	7	Leakage 9 gallons per minute.
	10.00 a. m.	8½	Leakage decreasing.
	3.30 p. m.	10½	Leakage decreasing, but still sufficiently bad to render pipe unsafe in practice. Water shut off and pipe allowed to soak.
Mar. 7	8.00 a. m.	0	Water leaked out amounting to 26 gallons per hour.

The appearance of the pipe outside and the location and quantity of the leakage indicate that the Sylvester wash makes a better lining than the waterproof paint. On the Sylvester wash section of the pipe there were several streaks of absolutely dry concrete, whereas the P. & B. section showed moisture on all the surface except the top, which, as the pipe had been reversed in position, was the bottom during construction.

The reason for so much leakage through a so-called "waterproof" paint was explained by an examination of the inside of the pipe. It

was found that as the inside surface was rough, many indentations had simply been bridged over by the paint, and when pressure was applied these spots had yielded and allowed water to pass through.

The result of this test with the Sylvester wash is disappointing, and it is easy to conjecture what the leakage from the pipe would have been without the wash. The difference in leakage between the plastered pipes Nos. 1 and 2, and No. 3, which was washed, would seem to favor the application of a good plaster to the inside of all concrete pipes subjected to the pressure of water.

It was remarked in the tests of the pipes Nos. 1 and 2 that the leakage on the south side of each of these was very much greater than that on the north side. These pipes, although rolled over from where they were made, stood in the same relative position as to top and bottom as that in which they were made. It was at first thought that the action of the sun on the south side of these pipes for the five months during which they had remained in the yard had affected that side injuriously, but when pipe No. 4 was being tested it was observed that the greatest leakage occurred on the north side. On examination of this pipe it was found that it stood in the reverse position from that in which it was made—that the bottom of the pipe now stood uppermost.

It is evident, then, that it was not the fact that the pipes had stood so long under the rays of the sun in the yard after being made that had affected the south side injuriously, because in pipe No. 4 the north side instead of the south side seemed to have been affected. As all the pipes were made on the same spot it is probable that it was the greater evaporation on the sunny side when the pipes were being made, especially at the tamping seam, that had affected them in this way, and all the experiments tended to corroborate this view of the matter. It would seem advisable, therefore, in making concrete pipes to hold water to insist upon their being made in the shade. As in the other pipes, the bottom of this pipe does not leak nearly as much as the sides, the moisture not being sufficient to cause any flow.

Pipe No. 4, Test 2.

As stated above, this pipe was coated on the inside with two coats of P. & B. waterproof paint on east half and with two coats of Sylvester wash on the west half. The first test was completed on March 7, 1904, and on March 28 this pipe was coated on the west end, over the Sylvester wash, with a plaster made of 1 part boiled linseed oil, 2 parts coal tar, 1 part sand, and 1¼ part cement; and on the east end over the P. & B., with a wash composed of 1 part of boiled linseed oil and 2 parts coal tar, enough to make a good, thick paint. This was laid on with a brush.

Test 2 of pipe No. 4.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Apr. 1	8.00 a. m.	0	Water turned into pipe.
	12.20 p. m.	.....	Pipe full; some sweat during filling process.
		10	Pipe commenced to leak.
		16	Leaked freely; less under plaster than under wasl
	12.40 p. m.	18	Leakage 6 gallons a minute.
	1.30 p. m.	19	Do.
	2.30 p. m.	21	Slight decrease of leakage; pipe sweating ov whole surface; pressure now cut to 4 pounds.
	4.30 p. m.	5	Pressure increased; leakage 2.75 gallons per minut

It has been suggested by a great many engineers and practical me in the pipe business that fine clay or ashes, or both, deposited in th water passing through the pipe would eventually seal up all the leak and make the pipe practically tight.

It was determined to test this theory, and accordingly a small stu fing box was placed on one of the cast-iron heads, and an agitator i the form of a small rake with a handle of half-inch round steel, worl ing in the stuffing box, was added to the equipment, so that the cla was kept stirred up when the pipe was under pressure.

It was determined to make a close examination of all the pipes teste up to this time, with a view to putting them in shape for testing some more theories of making steel-concrete pipe impermeable in actual practice. During the examination it was found that in order to make the pipes serviceable for further tests it would be necessary to chisel out the longitudinal cracks which had been developed in pipes Nos. 3 to 5, inclusive, and fill up these cracks with a strong mortar. The cracks were accordingly chiseled out about 1 inch deep. In doing this three important facts were disclosed.

(1) Pipe No. 5 was not a hard concrete. It seemed to be of a crumbly nature, and it would have been easy to cut a hole through it.

(2) Some of the longitudinal cracks in pipes Nos. 3 to 5, inclusive, were found to be in radial planes through the longitudinal rods, but only at the rods which are placed on the sides of the pipe, in sections A, A, as shown in fig. 1, p. 16.

It is possible that in tamping, the longitudinal rods in sections A, A may have sprung a little and exerted a tensile strain at these points in the material of the pipe, rendering them the weakest places when the additional pressure of the water was turned on.

(3) The concrete in No. 3 was exceedingly hard, and the plaster had become loose in the bottom part of the pipe, so that it was an easy

matter to remove a strip 2 feet wide for the full length of the pipe. This strip was replaced with fresh mortar of the kind used on this pipe before.

PIPE NO. 5.

PIPE NO. 5, TEST 1.

The west third of the pipe was covered on the inside with one coat of a wash made by Mr. C. E. Richards, of Los Angeles, who claims to have a waterproof wash and plaster for concrete or brick walls. The middle third had one coat of plaster and one coat of wash, and the east third of the pipe had two coats of plaster. This pipe was made September 22, 1903, and treated inside by Mr. Richards March 9 and 10, 1904. The wash was applied on March 9 and the mortar on March 10. The plaster has a very smooth and oily appearance. The process is not patented, but is a trade secret.

Test 1 of pipe No. 5.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 12	10.50 p. m.	0	Water turned into pipe.
	12.30 p. m.	9	Slight leakage in west section, which was covered with wash only; remainder of pipe dry.
	3.30 p. m.	5	Pipe full. Several pin holes on south side of west third commenced spouting.
		9	Few pin holes appear in east section, where lining was plastered only.
		10	Few more pin holes in center section where lining is both plaster and wash.
		24	Leakage rapid.
	4.10 p. m.	25½	Leakage 6 gallons per minute.
	4.30 p. m.	28	Leakage 5 gallons per minute.
	4.40 p. m.	29	Leakage 4.5 gallons per minute.
			Pressure turned off; pipe allowed to remain filled with water.
Mar. 14	7.45 a. m.	0	Pipe quite dry on outside.
			Leakage without pressure inconsiderable.
		20	No leakage until this pressure is reached, when seams and pin holes spurt as on Mar. 12.

As this pipe had leaked so much in first half hour under pressure, the experiment was concluded.

PIPE NO. 5, TEST 2.

In the first test of this pipe it was coated on inside with Richards wash and plaster as follows: West third, one coat of wash. Middle third, one coat of plaster and one coat of wash. East third, two coats of plaster.

n March 22, 1904, this pipe received on the east and middle thirds dditional coat of plaster. This plaster was composed of 1 part ent, 1 part screened sand, and one-fourth part lime putty moistened ı iron water. When dry it was covered with a light wash of iron cement. On March 23 the west third received a coat of Richards ter.

Test 2 of pipe No. 5.

te.	Hour.	Pressure.	Observations.
		Pounds.	
29	4.15 p. m.	18	Leaks begin to show on outside.
		20	Leaks quite free. Numerous pin holes near the top in "iron plaster" region of section, while Richards plaster section remains dry.
		25	Richards plaster section begins to show leakage, though not as much as remainder of pipe. Total leakage 4½ gallons per minute.
	4.40 p. m.	28	Leakage same. Pressure reduced to 12 pounds for night to prevent too much leakage.
30	8.00 a. m.	23	Leakage 1 gallon per minute. Thirty per cent of this leakage from cracks in the plasters on the end of the pipe where pressure under gasket has affected them.
	8.00 a. m.	30	No perceptible increase in leakage.
		34	Strong leakage at 2 spots on south side at junction of 2 plasters. No pin holes.
	9.00 a. m.	36	Leakage 3 gallons per minute. Ditches running to weir and submerged surface of weir sustained heavy deposit of laitance.
	10.00 a. m.	36	Leakage 3 gallons a minute.
	11.00 a. m.	36½	Do.
	12.00 m.	37	Do.
	2.00 p. m.	37½	Leakage 2.75 gallons per minute.
	3.00 p. m.	37	Do.
	5.00 p. m.	37	Do.
			Pressure reduced to 8 pounds for the night.
31	8.00 a. m.	14	Leakage ¾ gallon per minute. General sweat on the pipe. Full city pressure turned on and gage raised at once to 35 pounds.
	8.30 a. m.	36	Leakage 2½ gallons per minute.
	9.00 a. m.	36	Same leakage. Force pump applied.

'he pressure could not be raised above 39 pounds with the pump, ıough the pin holes did not spout. As the test was very satisfactory pipe was emptied. It showed considerable laitance on the outside l a slight tendency to close up, but leaked too much in the first 24 ırs to make a safe pipe for practice.

PIPE NO. 5, TEST 3.

This pipe was now coated inside with two coats of a tufa elastic paint, claimed by the proprietor to be an impermeable material. The first coat was applied July 27; second coat applied August 4.

The results of the third test of pipe No. 5 were as follows:

Test 3 of pipe No. 5.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Aug. 10	11.45 a. m.	.....	Water turned into pipe. When pipe was nearly full small leak developed at west end.
	3.50 p. m.	.....	Pipe filled; when air cock was closed pressure raised nearly 25 pounds. Leakage appeared to be at joint near top on south side; also along bottom.
		30	Leakage began on north side near top and along bottom. Few leaks on sides and 1 pin hole. Bottom leaked quite freely.
	4.30 p. m.	34	General sweat all over pipe. Most leakage along two seams in the bottom.
	5.00 p. m.	34	Leakage same. Pressure maintained over night.
Aug. 11	.....	30	Leakage 1¾ gallons per minute. Only two places where there was an appreciable flow except in bottom where there was a strong drip.
	10.30 a. m.	32	Leakage 2 gallons per minute. No appreciable change in appearance of pipe.
	11.00 a. m.	36	Leakage 2.2 gallons per minute.
			Before this test was commenced three large cracks were observed on the outside of the pipe, two of them being at the junctions of the top layer with the sides, running the full length of the pipe. The third crack extended one-half the length of the pipe and was in the center of the top layer. None of these cracks showed on the inside, nor did any of them leak under a pressure of 34 pounds.

Thirty-six pounds pressure seems from the above tests to be a measure of the efficiency of the tufa elastic paint. The same pipe leaked 2½ gallons per minute in test 2 under a pressure of 36 pounds.

When the heads were removed from the pipe it was found that the paint was covered with blisters, ranging from one-eighth to three-fourths of an inch in diameter. There were also many blotches of wrinkled surfaces. As the pipe dried out on the inside a number of surface checks developed, similar to those which occur when paint is put on any surface too thickly.

It must be admitted that all of these tests made on washes or paints gave very poor results; nor is this to be wondered at when it is con-

sidered that a wash or coat of paint is generally so thin that water under pressure is sure to penetrate it sooner or later, unless it were in the nature of a glaze. A glaze, however, being generally put on with heat, is necessarily impracticable for pipes such as are required for use in the Reclamation Service.

PIPE NO. 6.

Pipe No. 6, Test 1.

This pipe was coated on the inside east half with a wash of pure cement (Ideal). No wash or coating on west half.

Test 1 of pipe No. 6.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 9	2.15 p. m.	0	Water turned into pipe.
	4.00 p. m.	0	No leakage in washed section. Pronounced leakage in unwashed section, though not so much as in previous tests at the same stage of filling. Leaks mostly in "tamping seams." Pipe left for the night with small quantity of water flowing in, to soak it up gradually.
Mar. 10	9.00 a. m.	0	Full head city pressure turned on Leakage at imperfect places in unwashed section greater than supply from city main. Pipe emptied for complete inside coating.

Pipe No. 6, Test 2.

The pipe leaked so badly during the first test in the unwashed portion that it was impossible to fill it with a hose delivering 11 gallons of water per minute. The west half was covered with two coats of Sylvester wash and cement mixed, and the east half was covered with an additional coat of pure cement wash, which, with the two coats applied in the first test, made three coats of pure cement wash on east half. These coats were applied March 10 and 11. At 8 o'clock on March 16, 1904, water pressure was turned on and the pipe leaked 6 or 7 gallons per minute under 17 pounds of pressure. The leaks were principally through seams, and as they showed no appearance of diminishing by noon the pipe was emptied and the heads were removed to No. 2 for a second test of that pipe. It is quite evident from this test that a wash alone on the inside of a steel concrete pipe is not so effective as a plaster. It is possible, however, that a wash on top of a plaster might be a good thing, and another test will have a bearing on this subject.

PIPE No. 6, TEST 3.

This pipe, when last tested, had on the inside three coats of pure cement wash on east half and two coats of cement mixed with Sylvester wash on west half, and the result of the test being unsatisfactory, on March 21, 1904, another coat of cement mixed to a thick paint with boiled linseed oil was applied, and on March 22 another coat thicker than the first. The two coats required 40 pounds of cement and 3¼ gallons of oil.

Test 3 of pipe No. 6.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
Mar. 26	2.00 p. m.	.....	Pipe filled. No leakage during filling.
		18	Strong leakage develops on both sides, where the bottom section joins; remainder of pipe absolutely dry.
	2.00 p. m.	20	Same conditions.
	2.40 p. m.	.....	Slight leakage south side at junction of sides and top section, 5 gallons per minute.
	3.00 p. m.	.....	Two small leaks on north side near top section.
	3.15 p. m.	.....	Pressure reduced to 6 pounds.
	3.30 p. m.	6	Leakage 2½ gallons per minute.
	4.45 p. m.	8	Leakage 2 gallons per minute.
Mar. 27	4.40 p. m.	11	Leakage 1½ gallons per minute.
Mar. 28	7.45 a. m.	8	Leakage 1½ gallons per minute. Full city pressure now turned on.
	8.45 a. m.	20	Leakage 4½ gallons per minute. Test unsatisfactory. Pipe emptied.

It is quite evident to the writer that washes of any kind, unless in the form of a glaze or a soluble glass, are ineffective for making a concrete pipe impermeable. Even if they were effective at first, the coating, being so thin, would soon be worn away by the high velocity of the water, which is necessary for economy in most projects in the reclamation work.

PIPE NO. 7.

PIPE No. 7, TEST 1.

The pipe was composed of 1 part cement, one-half part lime paste, 3 parts sand, and 6 parts small gravel. It was completed on October 17, 1903, and was well seasoned with water for several days after completion. It remained undisturbed where it was made.

On June 13, 1904, about 100 pounds of fine clay were placed in pipe No. 7 and the heads fastened on the ends of the pipe.

Test 1 of pipe No. 7.

Date.	Hour.	Pressure.	Observations.
		Pounds.	
June 13	3.30 p. m.	.....	Water turned in.
	5.00 p. m.	2	Pipe commenced to leak on bottom. Inflow reduced to allow the pipe to fill slowly during the night.
June 14	8.00 a. m.	.....	Pipe leaking badly. Leakage very muddy from stirring up of clay. Clay stirred all day.
	4.45 p. m.	.....	Pipe full and leaking like a sieve.
June 15	8.00 a. m.	.....	No change.
	5.00 p. m.	.....	Water turned off; clay stirred.
May 16	8.00 a. m.	.....	Water turned on; 3 hours required to fill pipe, showing amount of leakage during night.
	11.00 a. m.	2	Pores closed up somewhat.
	2.00 p. m.	0	No pressure. Increased leakage.
	5.00 p. m.	.....	Water turned off for night.
June 17	8.00 a. m.	.....	Water turned on.
	10.40 p. m.	.....	Pipe full, showing less leakage than on previous night.
	10.40 p. m.	4	
	10.45 p. m.	3	Remained at this pressure all day. Clay stirred constantly. Pressure left on all night.
June 18	8.00 a. m.	3	Considerable laitance. Number of clay streaks on outside of pipe.
	3.30 p. m.	.....	Pipe emptied.

This pipe was tested for six days, and the closing up of the pores by lime deposits and clay combined apparently did not raise the pressure more than 3 pounds. During all this time the pipe leaked so badly as to demonstrate its entire unfitness for practical purposes. This experiment will serve to give an idea of the value of clay for stopping up the pores of concrete under the pressure of water.

PIPE NO. 7, TEST 2.

When the heads were removed from the pipe on the completion of the first test, the inside of the pipe was thoroughly washed to remove all traces of the clay, and on June 21 a plaster composed of 1 part cement (Ideal), 1 part marble dust, and 1 part fine screened sand was placed about one-fourth inch thick on the inside surface of the pipe for a length of 17 feet from the east end.

The remaining 3 feet of inside surface at the west end of the pipe was covered with Richards plaster of same thickness (one-fourth inch).

The plaster was kept well moistened till noon, when a thick grouting of equal parts of cement and marble dust was painted over the plaster so as to fill up all the places where the trowel had pulled and a few checks had developed by too quick setting. This plaster and wash was kept well moistened until June 25, when at 1 p. m. the heads were put on and filling commenced.

At 3 p. m. there was great difference between this filling and the previous one, as there was no sign of leakage up to this time, and the pipe was about half filled.

At 5.10 p. m. the pipe was filled, and when the air pipe was closed the pressure slowly rose to 14 pounds, and in a few minutes the pipe leaked freely over most of its surface. Most of the leakage came through the bottom layer, and at 5.25 p. m. the gage had dropped to 11 pounds. The pressure was allowed to remain on full till Monday morning.

June 27, at 8.30 a. m., the gage registered 12 pounds, and the leakage was nearly 7 gallons per minute. The pressure was reduced to 5 pounds, and kept at that for the remainder of the day.

June 28, at 8 a. m., the pressure had risen to 7 pounds during the night, and the leakage amounted to 3 gallons per minute.

The pressure was now turned on full, but the gage rose to only 13 pounds, and in a few minutes dropped to 12 pounds; the bottom leaked as freely as before, though the sides and top did not leak as much as before.

It seems strange that the bottom part of this pipe should leak so badly, as in the other pipes the top and bottom sections, which were tamped in the line of pressure, leaked much less than the sides, which were tamped at right angles to the lines of pressure. The pressure was kept on full until noon, when it was reduced to 5 pounds, and held at that during the balance of the day and night.

On June 29 the pipe dried off a good deal under the reduced pressure, but the bottom leaked freely, and the top was moist in spots, while the sides were practically dry. Considerable laitance had formed where the water had leaked out and run down over the sides.

On June 30 the pressure at 8 a. m. was 7 pounds and there was no material change in the action or appearance of the pipe, and when full pressure was put on the leakage was just as great as before.

The pipe was kept filled and under pressure of about 5 pounds until July 8; the city pressure was turned on occasionally, but the greatest pressure attained during this time was 15 pounds. All of the leakage of consequence was through the bottom section.

As this pipe leaked too much for practical purposes the water was turned off and the experiment concluded.

SUMMARY OF FIRST 19 TESTS.

In looking over the results of the first 19 tests one thing seems re—any pipe of this diameter and of great length would have many perfections, many of which can not easily be avoided. The greater rt of the leakage in nearly every case in these tests came from the mping seams, and by this method of constructing the pipes these ams are almost a necessity. If there are to be seams at all, would not be better to make them where they can be seen and made tight ainst leaking, so that more attention may be given to the remainder the pipe, both in the material of which it is composed and in the plac-g and tamping of this material afterwards? The great difficulty in e way of making a large pipe of steel concrete continuous is that ere are not only longitudinal tamping seams from short delays nec-sarily incident to this method of construction, but there are in addi-on cross seams wherever the work may stop for the night or for a y or more, for Sundays, holidays, or on account of bad weather or her unforeseen causes.

This naturally leads to the conclusion that the pipe might be more sily and economically made in short joints, and put together in the ench afterwards. By this means the tamping could be done continu-usly in each joint, so that there would be no leakage from tamping ams between joints, and special attention could be given to the joints, order to render them water-tight under ordinary pressure.

A longitudinal seam is much more likely to leak than a vertical am in pipe under pressure, because the pressure tends to open the ngitudinal seam while it does not necessarily tend to open the verti-al seam unless the pipe is built on a vertical curve, and this must be uarded against or provided for, if necessary, by taking up the ngitudinal strains with steel rods or cables. This method would llow more care to be taken with the mixing and placing of the aterial and the tamping of it, and would probably result in a much nore perfect pipe between joints. There are, however, many practi-al difficulties in the way of constructing such a pipe of large diameter nd great thickness of shell. One of the principal difficulties is to old the lengths of pipe together till the connection can be made. Another is the handling and placing of such heavy pieces of pipe with-ut injuring them; a third difficulty is that of making a water-tight oint without creating a rough or uneven surface in the waterway.

To put all these matters to a practical test another pipe was con-structed during the months of May and June, 1904. This pipe, which is called No. 8, was built in four pieces, each 5 feet in diameter inside, with a shell 6 inches thick, and with steel armor, as in the other pipes, in the center of the shell, and each piece was 5 feet long.

PIPE NO. 8.

COMPOSITION.

The composition of the sections of pipe No. 8 is as follows:

Section 1 was composed of Gillingham cement, 4 cubic feet; marble dust, 1 cubic foot; fine sand, 3 cubic feet; gravel, 20 cubic feet; or, 1 part cement, 1 part sand, and 5 parts gravel. The cement and marble dust were mixed through a fine screen, then mixed with the gravel and sand and turned six times dry, then turned four times wet. The concrete was so made that water came to surface after long tamping.

Section 2 was composed of Gillingham cement, 4 cubic feet; marble dust, 1 cubic foot; sand, 3 cubic feet; gravel, 20 cubic feet; lime putty, 3 gallons. The cement and marble dust were mixed as in section 1. Lime putty, passed through fine screens and dissolved in 12 gallons of water, was added during wet mixing. The material was mixed the same number of times as that for section 1, but it was made wetter.

Section 3 had the same composition as section 2, except that to lime putty was added an equal amount of Richards putty.

Section 4 was composed of Ideal cement, 4 cubic feet; marble dust, 2 cubic feet; sand, 4 cubic feet; gravel, 20 cubic feet—well screened and mixed. The material was dry mixed four times, wet mixed three times; 12 gallons of lime putty diluted in 24 gallons of water were added for wet mix.

All of these joints were made by continuous tamping, and every possible care was exercised to produce a good piece of work. They were all well seasoned by constant wetting and protected from the rays of the sun. The sections were made with a projecting bead at one end and a corresponding groove at the other end, so that the bead on one section would fit into the groove on the next section. In addition to this arrangement, a semicircular trench about 1 inch in diameter was left in the bead at one end, and another in the groove at the other end, so that when two sections are placed together these two semicircular trenches will form one circular opening 1 inch in diameter running clear around each joint. When the sections are pulled tightly together this opening can be filled up with cement grout or with any fluid material which may be decided upon as adding to the impermeability of the joint.

Fig. 2 shows the arrangement of sections before joints are closed. These sections were made with the intention of having six longitudinal steel rods run through them, to be fastened with sleeve nuts joining the ends of these rods in adjacent sections, large niches being left on the inside of the pipe at each joint where the sleeve nuts could be tightened. This arrangement would not work satisfactorily and was abandoned for a much simpler one. Through each section of pipe is

run lengthwise six pieces of three-fourths-inch gas pipe, which serve as guides for the rings of steel, to which they may be fastened with copper wire. The sections being all made on one form, these pipes can be kept so closely to their proper position that there is no difficulty in running a piece of one-half-inch wire cable through them when the sections are placed in position for jointing.

The sections are laid as closely together as may be necessary to allow the mortar for the joint to be put in place between them, and are then drawn together by fastening cables through a wooden frame at

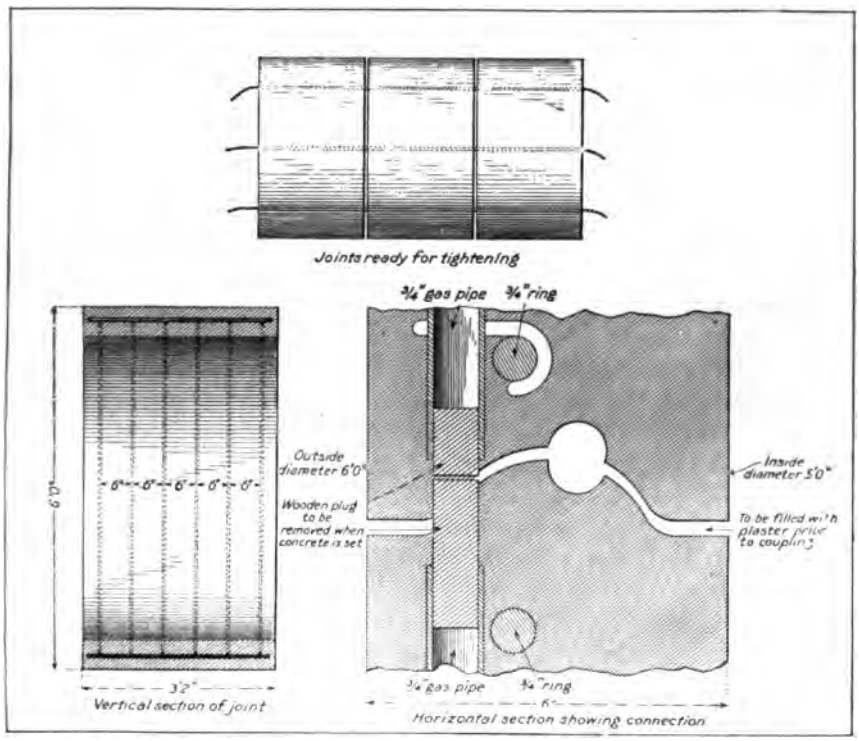


FIG. 2.—Sections of pipe showing methods of connection.

one end of the sections to be joined, and tightening up at the other end by a jackscrew working between two wooden frames, one of which rests against the last section, the other having the ends of the cables fastened to it with clamps, which can be readily removed when the joints are well closed. In the case of pipe No. 8, four sections were tightened up at the same time, and there was no difficulty in bringing the sections together with this length of pipe (20 feet). By this method it would be necessary to have at the end of each 20 feet, or whatever length proved practicable for tightening, a special screw-end rod con-

nection for the cables, about 2 feet long, so that the cable for the next length of pipe might be easily connected with that already tightened. It is most important that the ends of the sections should be made square with the longitudinal axis of the pipe.

PIPE NO. 8, TEST 1.

On July 28, 1904, this pipe, composed of four sections, was filled with water at 11.30 a. m. During the filling section 3 showed a little sweating near the bottom, caused probably by a small crack made while this section was being rolled to its proper place, and all the joints showed a little moisture through the openings that run round the joints and that were recently filled with grout. This grout was composed of 1 part cement, one-fourth part marble dust, and 1 part sand. The joints and niches inside were all filled with Richards mortar. When the air pipe was closed the pressure rose to 15 pounds. Section 1 showed a slight sweat in a short time, but no pinholes, and it was fully half an hour before it became moist over most of its surface. In one hour it was sweating all over.

Section 2 gave about the same results as section 1 until the pressure had been on for ten minutes, when it cracked in three places at the south end for a distance of about 1 foot, and the water leaked out so fast that the pressure would not go above 20 pounds. In one hour the whole surface was sweaty. Section 3 showed sweat developing soon after the pressure was turned on, and in fifteen minutes had a general sweat that at 19 pounds increased to a strong drip.

Section 4 showed absolutely no leakage or sweat for half an hour after being filled, then a slight sweat started on the top, and in one hour this sweat had spread over about one-fourth of its surface. This section was made with Ideal cement.

All the joints sweated a little through the pockets where the grouting was yet fresh and slightly checked, but at no part of the joints did the leakage amount to a flow.

At 2 p. m. there was not much change except that sections 1, 2, and 3 were entirely covered with laitance under a uniform pressure of 18 pounds. Section 4 showed a slight increase of sweat but no laitance except close to the joints, where there was a strong sweat through the pockets.

At 4 p. m. conditions were not materially changed.

At 5 p. m. the pressure was reduced to 8 pounds, and the pipe was left under that pressure all night.

On July 29, at 8 a. m., the gage registered 10 pounds, and as soon as full pressure was turned on it rose to 20 pounds and remained at that for several hours, when it dropped to 18 pounds. There was no change in sections 1, 2, and 3, while section 4 showed a slight sweat

over three-fourths of its surface and no laitance except at the joints. Sections 1 and 2 showed considerably more laitance than section 3.

City pressure was kept on full, and at 5 p. m. no material change was apparent in the pipes, except that section 3 did not seem to drip as much as at first. Section 4 still had one large dry space on each side. The pressure varied all day from 17 to 19 pounds. At 5 p. m. the pressure was closed down for the night to 10 pounds. On July 30, at 8 a. m., the gage registered 12 pounds. When pressure was turned on full it rose to 18 pounds. Section 3 appeared to be closing up and section 4 had not materially changed. By damming up the flow from the pipe and segregating the leakage from section 2, which was badly cracked, it was found that the other three sections leaked nearly 2 gallons per minute.

The water was then turned off and the pipe examined, and it was found that the cracks in section 2 extended clear through. They are supposed to have been caused by the sling which was used when turning the pipes over on their sides with the derrick.

Section 3 showed two checks inside on top, but they did not go clear through.

Sections 1 and 4 showed no cracks on the inside, while section 1 had several checks on the outside.

Section 4 had no checks either inside or outside. The Richards plaster in the inside joints was found to be good and firm and showed no disintegration. Before this pipe was broken up a jackscrew was placed under one end and the pipe was raised until it hung suspended at both ends. The joints were then examined and found to be in good condition. The pipe remained in this position for ten minutes, when the central joint opened one-sixteenth of an inch at the bottom but remained tight at the top. The cables had evidently stretched sufficiently to allow this action. The pipe was broken up about September 27, and it was found that the cracks on the outside on section 1, near the end where the leakage was so great, were caused by the omission of the last steel ring during construction, leaving a space of nearly 1 foot in length at that end without any strength except that of the concrete, which naturally could not stand the strain.

When the joints were broken it was found that there was not as good a bond between the grout and the pipes as there should have been. The core would sometimes adhere to one section of the cavity and make a clean break along the line of the other joint so as to show the shape of the mold. The plaster in the joints should be allowed to harden for at least two days before the grout is forced into the cavity; the grout may be made very wet. The hole should first be filled with water in which a little cement is mixed and allowed to stand filled for an hour, and then blown out and filled with grout.

While this experiment was not at all satisfactory on account of the accident in handling section 2, it shows that, with care and attention to details, this method of constructing pipes might be adopted in case no better one is found.

SMALL PIPES.

Some further experiments were made for the purpose of ascertaining the best mixtures for impermeable concrete, and for this purpose several small pipes were made with various mixtures and carefully tested.

These smaller pipes were all made in the same mold, each being 8

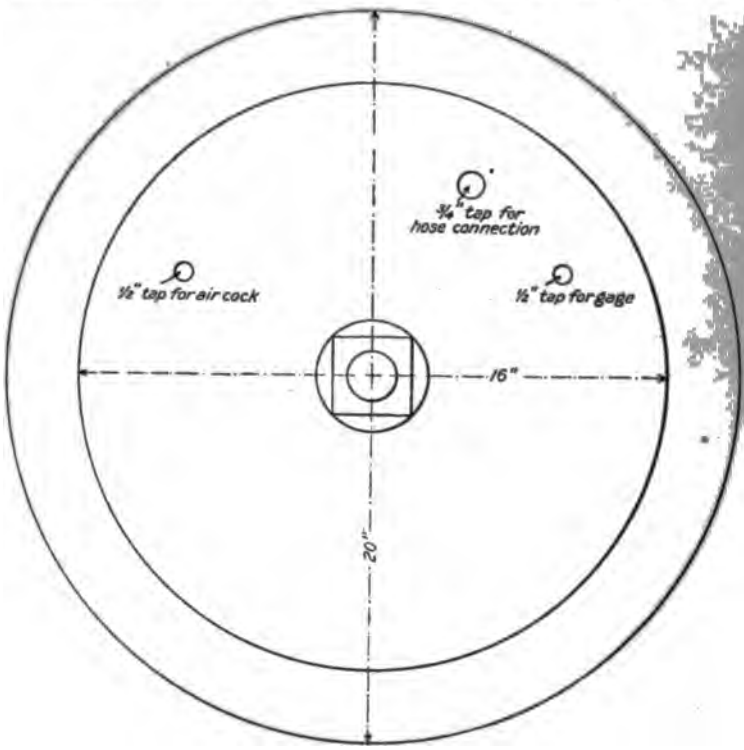
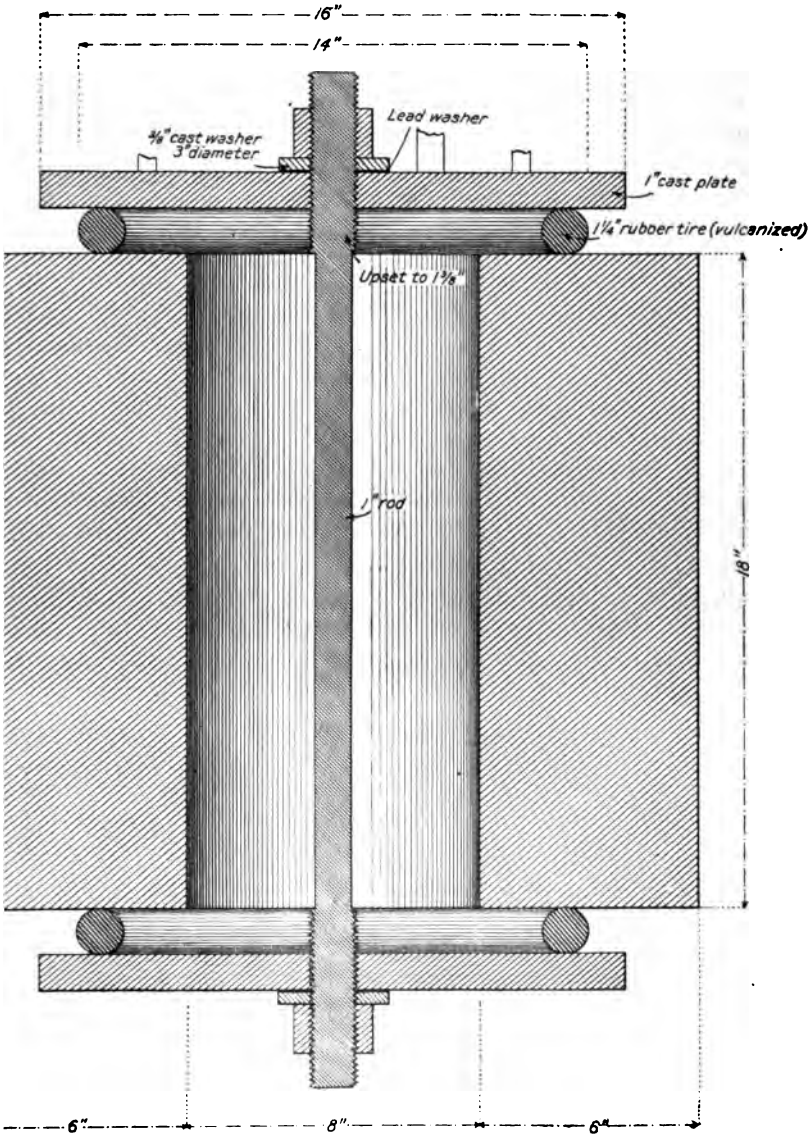


FIG. 3.—Elevation of end of small pipes, with cover, used for determining permeability of different mixtures of concrete.

inches in inside diameter, 6 inches in thickness of shell, and 18 inches long. The ends were made perfectly square to the axis and as smooth and true as possible. To the ends of these pipes were fitted small cast-iron disks, 1 inch thick, resting upon rubber-tire washers, vulcanized at the junction of the ends. The plates were drawn tightly on the washers by one central rod with a screw end to which a nut was fitted, substantially as shown in figs. 3 and 4.

The upper plate had connections for pipe from water tap, for air, and for gage as in the larger pipes.

hree of these pipes were made of each mixture, and nine different tures were tested. The three pipes for each mixture were marked " "B," and "C," respectively.



.—Horizontal section of small pipes used for determining permeability of different mixtures of concrete.

lixture No. 1 consisted of sand 2 parts (screened through 14-mesh en), gravel 3 parts (mixed sizes), cement (Ideal) 1 part, and marble t 1 part—all measured loose.

PIPE A, MIXTURE NO. 1.

This pipe was made August 17, and brushed inside and out with a cement wash. It was kept well wet for several days until thoroughly seasoned. On October 19 water was turned on, the pressure varying from 40 to 56 pounds for six hours. During this time the pipe showed no sweat or leak, but in one of the sudden jumps of the pressure from 40 to 60 pounds the pipe burst and stopped the test. Owing to the fluctuation of the pressure in the water pipes this was not a very satisfactory test, but showed incidentally that the tensile strength of this mixture was at least 40 pounds per square inch.

PIPE B, MIXTURE NO. 1.

This pipe was made on August 17. It was not washed with cement inside or outside, but was kept moist for three weeks and remained in the shade till October 20, when it was tested.

At 8.30 a. m. water was turned on and pressure allowed to rise to 40 pounds, and maintained as near that point as possible. In one hour a slight sweat showed near the bottom, and in four hours this sweat had spread over most of the surface. The pressure was then allowed to rise to 55 pounds, and a general sweat spread over the entire surface. This pressure was maintained for two hours more, and then the pipe burst during a sudden fluctuation of pressure from 45 to 62 pounds.

It was now decided to use two steel bands for clamping around the pipes during the tests, to prevent the bursting of the pipe under water hammer.

PIPE C, MIXTURE NO. 1.

This pipe was made August 18, and kept in the shade and well moistened until October 20, when it was tested. It was not washed with cement. At 3 p. m. water was turned on and the pressure regulated to 30 pounds. There was a flaw in the inside of this pipe caused by the material sticking to the core when the latter was being drawn out. The water seemed to enter this flaw, and caused a sweat at that place, and in two hours this sweat had spread over most of the surface of the pipe. At 5 p. m. the pressure was turned off and the pipe left filled with water for the night.

On October 21 the pressure was kept at 35 pounds from 8 till 10 a. m. The pressure was raised to 45 pounds, fluctuating between 43 and 55 pounds for two hours, during which time the pipe leaked 7½ gallons of water. The outside bands were now put on the pipe and the full city pressure turned on. The gage fluctuated between 43 and 62 pounds for the remainder of the day and until next day at noon, but there was no apparent increase in the amount of leakage. This pipe was not in good condition, but was tested for the sake of trying

the effect of the steel bands on the outside in preventing bursting under fluctuating heads. In this case they seemed to answer the purpose, but in many of the succeeding tests they did not prevent the pipes from bursting under much lower heads.

As the object of the experiments was to ascertain at what pressure sweating commenced, and as this point was in nearly all cases less than 40 pounds, the breaking of the pipe at a higher pressure than this was not of so much consequence.

The composition of the various mixtures and the pressure at which the sweating first became visible are shown below.

RESULTS OF TESTS OF SMALL PIPES.

It is not claimed that these pipes would not have sweated and leaked under lower pressures maintained for a long time; but in nearly every instance the sweating showed at the recorded pressure inside of one hour from the time the water was turned on.

Mixture No. 1.—Sand 2 parts, gravel 3 parts, cement 1 part, marble dust 1 part.
Pipe A, no sweat under 55 pounds (washed inside and out with cement wash).
Pipe B, sweat at 40 pounds (not washed with cement).
Pipe C, sweat at 30 pounds (not washed and had flaw inside).
Mixture No. 2.—Sand 3 parts, gravel 4 parts, cement ⅔ part, marble dust 1½ parts.
Pipe A, sweat at 60 pounds (washed inside and out with cement wash).
Pipe B, sweat at 45 pounds (not washed with cement).
Pipe C, sweat at 30 pounds (washed on inside with cement).
Mixture No. 3.—Sand 3 parts, gravel 4 parts, cement ⅔ part, marble dust 1½ parts, lime putty ½ part.
Pipe A, sweat at 35 pounds (washed inside and outside with cement).
Pipe B, sweat at 30 pounds (not washed).
Pipe C, sweat at 30 pounds (washed inside with cement).
Mixture No. 4.—Sand 3 parts, gravel 4 parts, cement 1½ parts, hydrated lime ½ part.
Pipe A, sweat at 30 pounds (washed inside and out with cement).
Pipe B, sweat at 35 pounds (not washed).
Pipe C, sweat at 35 pounds (washed inside with neat cement).
Mixture No. 5.—Sand 3 parts, gravel 4 parts, cement 1 part, marble dust 2 parts, lime putty ½ part.
Pipe A sweat at 50 pounds (washed inside and out with neat cement).
Pipe B sweat at 35 pounds (no wash).
Pipe C sweat at 40 pounds (washed inside with neat cement).
Mixture No. 6.—Sand 2 parts, gravel 5 parts, cement 1 part, marble dust 1 part, Richards mixture 1 part.
Pipe A sweat at 40 pounds (not washed).
Pipe B sweat at 40 pounds (not washed).
Pipe C broke at 40 pounds. Without sweat for 45 minutes. (Not washed.)
Mixture No. 7.—Sand 2 parts, gravel 5 parts, cement 1 part, marble dust 1 part, lime putty ½ part (with Richards mixture).
Pipe A sweat at 35 pounds (no wash).
Pipe B sweat at 38 pounds (no wash).
Pipe C sweat at 40 pounds (no wash).
Mixture No. 8.—Sand 2 parts, gravel 5 parts, cement 2 parts, hydrated lime ½ part, marble dust ½ part.

Pipe A sweat at 35 pounds (no wash).
Pipe B sweat at 23 pounds (no wash).
Pipe C sweat at 23 pounds (no wash).

Mixture No. 9.—Sand 2 parts, gravel 5 parts, cement 1½ parts, hydrated lime ½ part, marble dust 1 part.

Pipe A sweat at 40 pounds (no wash). This pipe stood 65 pounds without breaking.

Pipe B sweat at 41 pounds (no wash). This pipe stood 57 pounds' pressure without breaking.

Pipe C discarded on account of flaw.

It is evident from these experiments that the impermeability of the concrete itself in a steel-concrete pipe must not be depended on too much, but it is better to cover the inside surface of the pipe with a thick coat, or probably better still with several thin coats of impervious mortar. This mortar must be soft and plastic when first placed on the pipe. The Richards plaster seems to be the nearest approach to this ideal plaster that has been found in these experiments.

The experiments on the small pipes were not carried out by the writer, who, on account of other duties, was unable to direct them. The assistant in charge of the experiments was a very careful, painstaking, and practical man of long experience in concrete work, and the experiments are given for what they are worth.

This entire subject is a most complex one, and it is realized that the results of these experiments are somewhat disappointing. It is hoped, however, that what little has been done may serve as a beginning for further experiments.

CONCLUSIONS.

The following precautions in making concrete pipes to withstand water pressure are suggested:

1. Do not allow the sun's rays to touch the concrete when it is being mixed and placed in the form. If necessary build a shed over the work.

2. If the steel-concrete pipe can not be made continuously by machine, do as much of the hand tamping as possible in radial directions. When the tamping must be done at right angles to the radius of the pipe, either in longitudinal or circumferential directions, avoid as far as possible the formation of seams or cleavage planes from delays in placing the forms and adding fresh material. By making the concrete very wet, delays will not be so dangerous as in the case of dry concrete.

3. Be careful in tamping not to spring the longitudinal rods, and use as few of these as will suffice to hold the circumferential rods in place, except in case of vertical curves in the pipe, when additional rods or steel cables must be used on the longer side of the curved part of the pipe.

4. Do not depend upon the tensile strength of the concrete, but

make the steel rods of such size and distance apart as will insure no greater stretch of the steel than 0.04 inch in any rod from the maximum pressure to which the pipe is to be subjected.

5. Make the inside diameter of the pipe 1½ inches larger than required, to allow space for putting two coats of plaster on the inside.

6. As soon as the pipe is completed give the inside one coat of plaster one-half inch thick, composed of 1 part cement to 1½ parts of sand, and a small quantity of lime paste, thoroughly cooled, to retard setting. Keep pipe well wet ahead of the plastering. When this coat, which may be left rough, is dry, put on another coat about one-fourth inch thick of plaster composed of 1 part of sand to 1 part of cement. This coat should be troweled to a smooth surface, and when it is dry the entire inside surface of the pipe should be covered with a thick wash of fine cement and water.

7. Provide for drainage of water which may leak when the pipe is first filled, so that sufficient water may not remain in the trench to soften the ground under the pipe.

8. Bury the pipe under the ground so that there will be in no place less than 2 feet between the top of the pipe and the natural surface of the ground.

9. In very cold climates provide means for draining the pipe, so that it can be emptied at the end of each irrigating season.

10. The soap and alum mixture may be used to advantage in making the concrete, but reliance for impermeability must be placed on the plastering rather than on the material of the pipe.

11. Do not use steel-concrete pipes for heads over 70 feet, except for short distances, where a 100-foot head might be used by taking special precautions.

It may be asked why, in view of the fact that a head of 70 feet is likely to crack a 5-foot steel-concrete pipe, it is recommended to build pipes of such diameter, for use under such a head. It may be answered that a steel-concrete pipe with a crack and a small, gradually decreasing leakage may be, and probably is, much more durable than a pipe made of steel, or of wood with steel bands or rods, and the leakage, under ordinary circumstances, may not be as much as is now found in many lines of cast-iron pipes in our large cities.

Under ordinary conditions, in all of the reclamation projects where pressure pipes may be used, the pipes will probably be under uniform pressure for all of the irrigating season. It is highly probable that cracks formed in these pipes when under pressure will be filled up with sediment and lime deposits during the irrigating season, which generally lasts several months. If serious leaks occur during this season, the blow-off and drain pipes can be used to turn the water out of the pipe, so that it can be repaired inside, and during the winter

time, when the pipe is empty, an excellent opportunity is afforded to examine and make repairs in the inside of the pipe.

A 5-foot pipe under 30 pounds pressure, or approximately 70 feet head, if made with 1-inch rods, instead of three-fourths-inch rods, with $3\frac{3}{8}$-inch center distances, would cost about $2.50 a foot extra, and the only gain would be that the stretch of the steel would be 0.023 inch, instead of 0.040 inch for the three-fourths-inch rods. Theoretically, when steel-armored concrete pipe is subjected to internal pressure, the materials of which it is composed must yield or stretch within certain limits. As the stretch of concrete is so small that it has never been measured, we must rely upon the steel to take up the stresses caused by the internal pressure in the pipe. If a steel-concrete pipe is designed to bear with safety 30 pounds per square inch internal pressure, and the steel in the pipe is calculated to take up all the stress due to this pressure, with a factor of safety of 4 for steel of an ultimate strength of 60,000 pounds, and if the pipe is 5 feet diameter inside, and the steel rods three-fourths-inch diameter, these rods would have to be spaced 7.33 inches from center to center.

Let us determine what the stretch in this steel would be in one rod under these conditions.

The stretch in inches = total stress in pounds on 7.33 inches in length of pipe × original length in inches ÷ modulus of elasticity in pounds per square inch × area in square inches; therefore stretch =

$$7.33 \times 30 \times 30 \times \frac{204}{35{,}000{,}000 \times 0.44} = 0.09 \text{ inch nearly.}$$

It is probable that this amount of stretch in the steel would cause one or more cracks along the full length of the pipe. If, however, the amount of steel is doubled, the stretch would be reduced by one-half, but this makes the pipe more expensive.

There would still be a stretch of 0.04 inch, and the consequences of this stretch might be guarded against by plastering with some material which would be more plastic than ordinary concrete, or by another method mentioned hereafter.

If this steel were distributed over the full length of the pipe in the shape of a sheet-steel riveted pipe, it would give thickness of $\frac{0.44}{3.66} = 0.12$ inch for the steel, and this pipe, if double riveted, would have a factor of safety of 5.6. This thickness is really more than is necessary for safety, but not more than is necessary for rigidity of form in a steel pipe of 5 feet diameter if used alone, nor for a steel-concrete pipe under the assumed pressure if the stretch is taken into account.

There can be no question that a steel pipe inside a concrete pipe would be tight, but it would be useless to put a lining of concrete inside the steel, as the concrete would certainly leak some, and the steel would be little better protected on the inside from the action of the water

than if there were no concrete inside. It would, however, be protected from scouring, and a ring of concrete outside the steel would protect the outside of the steel from the action of injurious salts, acids, etc. A better pipe, however, would be a wooden pipe with steel bands, which can be made perfectly continuous, smooth, and true inside, with a ring of concrete placed around it after the wood is thoroughly saturated and the leaks all closed up. This would be an expensive pipe, but it is believed that it would be as nearly an ideal pipe for a warm climate as could be made. With a factor of safety of 4 for the steel rods, the amount of steel would be reduced to half of that in the concrete pipe, and in the case of 30 pounds pressure this would amount to a three-fourths-inch rod 17 feet long for each 7.33 inches in length of the pipe, or $\frac{17\times1.5\times12}{7.33}=41$ pounds of steel per linear foot of pipe.

Concrete in a ring 3 inches thick around wood pipe would amount to $\frac{18}{4}=4\frac{1}{2}$ cubic feet per linear foot, so that the amount of money saved on the steel by using a wooden pipe would probably pay for the concrete used in covering it.

For a comparison of cost, then, we could have a wooden pipe with bands spaced for a factor of safety of 4, and 3 inches of concrete outside, as against a steel-concrete pipe with twice the number of bands and 6 inches of concrete. With steel at 4 cents per pound in place, concrete at 40 cents per cubic foot in place, and lumber at 7 cents per foot B. M. in place, the cost of these pipes would be about the same, and there is little doubt that the wooden pipe with a concrete envelope would be the better and more lasting pipe.

Another method for getting rid of the injurious effect of the stretch in the steel in a steel-concrete pipe (with a factor of safety of 4 for the steel rods) would be to make two well-defined joints in the concrete in a horizontal plane through the center and running the full length of the pipe.

A continuous sheet-steel dowel could project 2 or 3 inches into the concrete in each half of the pipe, and when the pressure came on the inside the stretch would probably take place at these joints and thus prevent all other longitudinal cracks from forming.

This dowel, which might be one-eighth by 6 inches, could be made in long lengths, overlapping a little at the ends and fastened by wire to the rods to keep it in its proper place. The concrete in the lower half of the pipe would end in a smooth, horizontal plane at the center line of this dowel on each side, and this plane might be allowed to harden for twenty-four hours, so that when the upper half of the pipe was made there would be a well-defined crack on each side. Of course this would increase the area subject to inside pressure by a small amount on each side, but this would be true of any other longitudinal crack.

It seems probable that this would prevent any other cracks forming, but it would be necessary to try this experiment before building any large amount of pipe on this assumption.

The durability of steel rods of large diameter, such as were used in these experiments, is yet undetermined, as the time between placing these rods in the concrete and the breaking up of the pipes was too short to afford reliable data for conclusions on this subject.

When the pipes were broken up none of the rods exhibited any appearance of rust, except one, which showed, at a point where there was a large and long-continued leak in the pipe, a small rusty place, about 1½ inches long, all around the rod. The pipe in which this occurred was lined with a mortar mixed with sal ammoniac and iron filings, and the presence of the sal ammoniac would naturally account for the rust.

Instead of steel rods electrically welded galvanized wire might be used for armor in concrete pipe. This wire is now manufactured in the United States, and could be used if the pipe were made in joints. It would not be suitable, however, if the pipe were made continuously, as in these experiments, on account of the difficulty of tamping and the stretch of the steel, and the consequent cracking of the concrete would still occur, so that the amount of wire needed in the hoops would probably make it too expensive to be considered.

If many of the results of these experiments have been negative, it may be some consolation to remember that it is sometimes quite as important to know how *not* to do a thing as to know how to do it.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 143.]

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of United States—folios and separate sheets thereof; (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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WS 117. The lignite of North Dakota and its relation to irrigation, by F. A. Wilder. 1904. 39
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WS 143. Experiments on steel-concrete pipes on a working scale, by J. H. Quinton. 1905. 61 pp., 4

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson
Twelfth Annual, Pt. II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Ann
Pt. III.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

July, 1905.

Water-Supply and Irrigation Paper No. 144 Series L, Quality of Water, 10

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE NORMAL DISTRIBUTION OF CHLORINE IN THE NATURAL WATERS OF NEW YORK AND NEW ENGLAND

BY

DANIEL D. JACKSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., December 20, 1904.

SIR: I transmit herewith a manuscript entitled "The Normal Distribution of Chlorine in the Natural Waters of New York and New England," by Daniel D. Jackson, and request that it be published in the series of Water-Supply and Irrigation Papers.

There is probably no more important feature involved in the establishment of municipal water supplies in States bordering on or situated close to the seacoast than the determination of normal chlorine. The availability of any water for such purposes depends largely upon its freedom from organic contamination. Chlorine is one of the ingredients of dangerous organic matter, and, as this element is extremely stable, it undergoes none of the chemical changes common to the other component parts of organic matter, and its determination furnishes reliable and persistent evidence concerning the pollution of any water.

A certain proportion of the chlorine in a water has its origin in natural causes, and has no relation to artificial pollution; therefore, in determining the character of a water for domestic purposes, it is necessary to consider this natural or normal chlorine, and whenever the chlorine present is in excess of the normal the evidence of past pollution is complete.

It has been found, moreover, that (with the exception of local deposits) the normal chlorine in natural waters is derived from the salt of the ocean, blown over the land by storms, and that it diminishes in amount as the distance from the ocean increases. This decrease is so definite that equal amounts of chlorine are found along lines generally parallel to the seacoast, thus affording a basis for the establishment of isochlors. In Massachusetts and Connecticut these lines have been located, and for several years the information has proved to be of great value to the water-supply interests of those States. The accompanying paper extends this information to the remainder of the New England States and to New York.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE NORMAL DISTRIBUTION OF CHLORINE IN THE NATURAL WATERS OF NEW YORK AND NEW ENGLAND.

By Daniel D. Jackson.

INTRODUCTION.

Chlorine, a constituent of common salt, is present in nearly all natural waters. Its original sources are mineral salt deposits and finely divided salt spray from the sea. This latter is carried with dust particles by the wind and precipitated with the rain. All salt found in waters not coming from these original sources comes from domestic drainage and indicates that the water either is at the present time polluted or was polluted and has since been purified. By a comparison of the salt content of any water under examination with the normal chlorine figure for that region the extent of past or present pollution may be determined.

PHYSIOLOGICAL FUNCTIONS OF COMMON SALT.

Salt always occurs in drainage from animal sources, because in all animal economy a certain fairly definite amount of common salt is eaten with the food daily and later expelled from the body in practically the same condition in which it was absorbed. That it plays an important rôle in the blood is indicated by the fact that on an average it constitutes about one-half of the total blood ash. It is also found that normal gastric juice can not be formed without the presence of salt, and that in many other secretions of the body its presence is probably a necessity.

SALT AS AN INDICATION OF POLLUTION.

The amount of salt in a water is a valuable indication of pollution because of the following facts: (1) The animal body expels the same amount of salt that it absorbs; (2) this salt is unchangeable in the soil and is very soluble in water; (3) it must eventually form a part of the drainage and become mixed with the general run-off of the region in which it is expelled. The average amount of salt entering the drainage of any particular district is so constant for each inhabitant that it has been claimed that the number of people living on a drainage area may be determined with a fair degree of accuracy from the average

run-off and the excess of chlorine over the normal. Stearns[a] estimates the chlorine in the run-off of any drainage area not receiving factory waste to be increased about one-tenth of a part per million by every 20 inhabitants per square mile.

SALT IN THE WATERS OF INLAND STATES.

All salt in natural unpolluted waters farther inland than Ohio comes from mineral deposits. The salt winds from the sea have no effect beyond this State, but unfortunately west of this State a large proportion of the natural waters are more or less affected by the salt deposits. The underground salt seems to spread over a broad area and exerts not only a wide but a variable influence over most of the waters. In these inland States, while the "normal chlorine" would be practically zero the value of the determination of chlorine is in most cases vitiated by the variable quantity of salt from mineral sources. Determinations of chlorine in samples of water taken above and below a city which runs its drainage into the stream examined may give the extent of pollution due to the city sewage, but the waters so far analyzed in the inland States give indications that the question of *normal* chlorine does not to any great extent enter into sanitary problems.

SALT IN COAST STATE WATERS.

On the other hand, the coast State waters are practically unaffected by this mineral salt, and, while very extensive deposits exist, especially in the State of New York, they are in narrow pockets and exert an influence over a very limited area. Except in these pockets the mineral salt has apparently been washed into the sea.

It is found that in the coast States the salt in the natural waters which comes from original sources is practically all brought in by the sea winds, and that a certain normal amount is present in the waters of each locality.

The difference in the normal amount in different localities is due to variations (1) in distance from the seacoast, (2) in the amount of rainfall, (3) in the rate of evaporation, (4) in the amount of protection from ocean winds, and (5) in the direction of the prevailing winds. In spite of the great variety of causes which affect the normal chlorine in natural waters, the normal for any particular region is surprisingly constant.

The chlorine decreases as waters farther and farther inland are tested, so that by connecting with lines on the map localities having the same normal we find that these lines of equal chlorine (isochlors) follow in a general way the coast lines, and as they extend inland are still more or

[a] Stearns, F. P., Rept. Mass. State board of health, 1890, pt. 1, p. 680.

less parallel to the coast. The distance of these lines from the coast depends chiefly upon the general direction of the wind and the protecting influences of mountains on the coast or of islands near the mainland.

COLLECTION OF SAMPLES.

In order to obtain the normal chlorine lines for any State it is necessary to first collect a large number of analyses for chlorine in waters taken at different seasons over the entire area to be covered. It is evident that near the seacoast, where the variations in chlorine within a limited area are greatest, the largest number of data must be collected. A large number of samples of water taken from surface and ground sources must be obtained. The pond waters usually give the best results, and careful inspection of the drainage area of such sources gives a good idea of whether or not the water is subject to pollution. Samples for analysis should be chosen as far from human habitation as possible.

SOLUTIONS REQUIRED FOR CHLORINE DETERMINATIONS.

The following solutions are employed in the analysis of water for chlorine:

Salt solution.—A solution of chemically pure fused salt, containing 1 milligram of chlorine in each cubic centimeter is made by dissolving 1.648 grams of the fused sodium chloride in 1 liter of distilled water free from chlorine.

Silver nitrate solution.—Two and one-half grams of crystallized silver nitrate are dissolved in 1 liter of distilled water free from chlorine. To this solution water or strong silver nitrate is added until by actual titration 10 c. c. of it are equivalent to 5 c. c. of the standard salt solution. One cubic centimeter of this solution is then equivalent to 0.5 milligram of chlorine.

Potassium chromate solution.—An indicator solution is made by dissolving 50 grams of potassium chromate in 1 liter of distilled water and then adding sufficient silver-nitrate solution to precipitate all the chlorine present and turn the precipitate slightly reddish. This is allowed to stand, and (by filtering or decanting) the clear solution is then obtained.

Emulsion of alumina.—This is made by dissolving 125 grams of potassium or ammonium alum in 1 liter of water and precipitating the alumina from the boiling solution by ammonia. After precipitation the alumina must be washed free from chlorine, sulphate, and ammonia by successive treatments, settlings, and decantations with cold distilled water.

METHODS OF PROCEDURE IN THE DETERMINATION OF CHLORINE.

Pour 25 c. c. of the water to be tested into a white porcelain dish. Add about one-half a cubic centimeter of chromate solution and run in standard silver-nitrate solution from a burette until the first faint reddish tint appears. This is more easily noted if, for comparison, a dish containing the same amount of water and chromate is kept beside the dish in which the test is made.

If one or more cubic centimeters of silver nitrate are necessary to reach an end point, the test may be made without evaporation, but if less is required, then evaporate 250 c. c. to 25 c. c. volume before making the test. It may at times be necessary to evaporate more than this if the chlorine present is very close to zero in amount.

It is best to always titrate with 25 c. c. of the water. In this case 0.1 c. c. is subtracted from the results as an indicator error. If more than this amount is used in titration, subtract 0.1 c. c. for each 25 c. c. of the volume of water titrated.

If 250 c. c. of water are taken, the number of cubic centimeters of silver nitrate solution used to obtain an end point minus 0.1 c. c. multiplied by 2 gives the chlorine in parts per million.

Example: 250 c. c. are evaporated to a volume of 25 c. c. and chromate solution added. In the titration 3.5 c. c. of silver nitrate are used. Then $(3.5-0.1)\times 2=6.8$. The water then contains 6.8 parts per million of chlorine.

If the sample is highly colored and very turbid, it may be necessary to clarify it by treating it with an emulsion of alumina. This is best accomplished by bringing the water just to the boiling point, and then adding alumina and shaking the emulsion. In a few minutes the clarified water may be decanted. This is allowed to cool and the required amount is measured out for titration.

OBSERVATIONS ON THE USE OF THE NORMAL CHLORINE MAP.

Having drawn a map of this character for any coast State we are then able to estimate the pollution in any natural water by the amount of chlorine present over the normal. In some instances it is first necessary to ascertain that the chlorine is not from mineral sources.

It will be seen that the normal chlorine lines are of great practical value both to the chemist and to the engineer, as they give an index from which may be estimated the sanitary quality of most waters analyzed within the coast States. The chlorine also furnishes information as to the source of deep-seated springs or artesian wells.

While this chlorine in the general run-off is in direct proportion to the population on a drainage area, provided none of the sewage is carried outside of that area, yet waters in this region may have been puri-

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Chlorine determinations for Maine.

[Parts per million.]

Source.	Chlorine.
Androscoggin County:	
Auburn, Lake Auburn	2.0
Curtis Corner, spring	2.0
Lewiston, spring	2.0
well	2.0
Lisbon, spring	2.5
Livermore Falls, spring	.8
Mechanic Falls, spring	1.5
water supply	2.0
Sabattus, spring	2.0
Turner, well	2.0
West Minot, spring	2.0
Aroostook County:	
Caribou, well	.3
Fort Fairfield, spring	.3
Fort Kent, spring	.3
Houlton, spring	.4
Presque Isle, brook	.3
Cumberland County:	
Ash Cove, spring	6.0
Brunswick, spring	2.8
water supply	4.0
Deering, spring	4.0
East Baldwin, well	2.0
Gray, spring	2.5
Growstown, spring	5.2
North Raymond, spring	2.0
Portland, spring	6.0
Pownal, spring	6.0
Saccarappa, well	5.0
Scarboro, spring	6.0
Sebago, lake	2.0
well	2.0
Walnut Hill, well	5.0
West Baldwin, spring	1.5
Westbrook, spring	4.0
Yarmouth, spring	6.0
Yarmouthville, spring	5.0
Franklin County:	
Avon, pond	.8

Source.	Chlorine.
Hancock County:	
Bar Harbor, Eagle Lake	
Brooklin, spring	
well	
Brooksville, spring	
Bucksport, well	
Castine, spring	
Lemoine, spring	
Sedgwick, Black Pond	
spring	
spring	
Upper Pond	
Kennebec County:	
Augusta, well	
Gardiner, spring	
Manchester, well	
Monmouth, spring	
Riverside, spring	
Waterville, China Lake	
Messalonskie Lake	
Messalonskie River	
Tobey Stream	
West Sidney, spring	
Winslow, spring	
Winthrop, well	
well	
Knox County:	
Camden, spring	
Rockland, water supply	
Thomasville, water supply	
Union, spring	
Warren, spring	
Washington, spring	
Lincoln County:	
Jefferson, stream	
Waldoboro, well	
Oxford County:	
Andover, spring	
Canton, well	
Dixfield, small brook	

Chlorine determinations for Maine—Continued.

[Parts per million.]

Source.	Chlorine.
xford County—Continued.	
Fryeburg, well	1.0
Gilead, reservoir	.6
Middle dam, Richardson Lake	.6
Upper dam, spring	.5
Welchville, well	1.0
West Bethel, spring	.8
enobscot County:	
Bangor, spring	1.5
Dexter, well	.7
Hampden, well	2.0
Old Town, spring	1.0
iscataquis County:	
Greenville, spring	.5
Guilford, spring	.5
agadahoc County:	
Bath, lake	4.0
spring	6.0
water supply	4.0
Bowdoinham, spring	4.0
Richmond, water supply	2.5
omerset County:	
Pittsfield, spring	1.0
The Forks, spring	.4
aldo County:	
Brooks, well	3.0
Stockton Springs	6.0
Swanville, well	5.0
Waldo County—Continued.	
Unity, reservoir	1.5
Winterport, well	2.0
Washington County:	
Baring, Spragues Falls	2.3
Calais, spring	4.0
Cherryfield, spring	4.0
Eastport, Chadburn dam	2.4
Perry dam	3.2
water supply	3.1
East Machias, lake	4.0
Edmonds, spring	4.0
Harrington, spring	6.0
Machias, spring	6.0
York County:	
Alfred, well	2.5
Cape Elizabeth, well	9.0
Cornish, spring	1.5
Eliot, spring	4.0
Hollis, well	3.0
Kennebunk, spring	5.0
well	6.0
Lebanon, well	4.0
Limington, spring	2.0
Lyman, spring	3.0
Old Orchard, spring	6.0
Sandford, spring	2.7
well	3.0
South Berwick, spring	3.5
Springfield, well	4.0

THE ISOCHLORS OF NEW HAMPSHIRE.

The New Hampshire isochlors (Pl. III) were drawn from observa-ions obtained by Mr. H. E. Barnard, chemist, New Hampshire State oard of health, and from the work of Mr. M. O. Leighton and the uthor.

The outlines follow the seacoast in a general way, but the inland nes (0.4 and 0.5 part per million) are deflected to some extent toward he coast by the influence of the White Mountains. The following is

an extract from Mr. Barnard's letter on the normal chlorine of N Hampshire:

I am inclosing the results of the chlorine determination of 570 waters, colle from 145 different towns. About 200 of these determinations, representing w from the southeastern part of the State, near the coast, were made on samples lected expressly for the chlorine work and are from supplies of known purity. T remainder of the examinations were made in the course of our regular work on s tary water analyses, and the results are selected from over 1,800 analyses. We confident that they represent normal chlorines, as they are mainly spring sup The chlorine factor was not accepted as normal, however, until complete sa analyses had proved the supply to be entirely free from contamination.

Some few results represent town supplies, and others are obtained from analy of small mountain streams. The incorporation of the results of analyses o water has been avoided because the chlorine content of an unpolluted river w frequently less than that of the town through which it flows, due, of course, fact that the river is fed by streams and ponds along the mountains wh normal chlorine is low.

The chlorine content of waters along the coast has been determined carefu is found to diminish so rapidly that 5 miles will frequently change the isochlor parts per million. This is, of course, true only near the coast. It may be argu that determinations of chlorine in water located directly on the coast have litt significance because of the liability of change of chlorine content when heavy storm sweep in off the sea. I have found that duplicate analyses, made at different season showed differences so slight that they were well within the limit of error. Refe ring to the chlorine map you have drafted, I am surprised that our isochlors agr so closely.

The following list gives the observations which have had a bearin upon the determination of normal chlorine lines in the State of Ne Hampshire:

Chlorine determinations for New Hampshire.

[Parts per million.]

Source.	Samples.	Chlorine.	Source.	Samples.	Chlorin
Belknap County:			Carroll Co.—Cont'd.		
Belmont	5	0.73	Lower Bartlett		0.
Center Harbor	1	.9′	Moultonboro		.
Gilmantown	1	.75	Mount Pleasant	2	.
Laconia	4	1.18	Ossipee	2	.
Meredith	1	1.0	Snowville	2	.
New Hampton	8	.79	Tamworth	2	1.
Tilton	9	1.0	Wakefield	1	2.
Carroll County:			Wolfboro	3	.
Bartlett	1	.75	Cheshire County:		
Do		.7	Chesham	3	.
Conway	3	.58	Dublin	5	.
Eaton	1	.75	Fitzwilliam	1	1.
Freedom	1	.75	Do		.
Intervale	1	.5	Harrisville	3	.

T S
RMONT AND NEW HAMPSHIRE.

Chlorine determinations for New Hampshire—Continued.

[Parts per million.]

Source.	Samples.	Chlorine.
heshire Co.—Cont'd.		
Jaffrey	.....	0.8
Jaffrey, East	4	.87
Keene	7	.85
Do	.....	.7
Marlboro	2	.88
Marlow	1	.5
Monadnock	1	1.0
Nelson	3	1.01
Troy	1	1.0
Walpole	2	.62
Winchester	1	.92
oos County:		
Berlin	3	.75
Colebrook	1	.5
Dummer	.....	.4
Erroll	.....	.3
Gorham	2	.75
Groveton	.....	.5
Jefferson	1	.39
Lancaster	2	.5
Stratford	2	.5
Whitefield	3	.43
rafton County:		
Alexandria	1	.60
Ashland	.....	.7
Bethlehem	7	.55
Do	.....	.6
Bridgewater	1	.75
Bristol	4	.77
Do	.....	.6
Campton	11	.65
Do	.....	.6
Canaan	12	.64
Do	.....	.7
Franconia	1	.5
Grafton	2	.74
Hanover	8	.78
Do	.....	.5
Haverhill	4	.6
Grafton Co.—Cont'd.		
Lincoln	3	0.46
Lisbon	4	.75
Littleton	15	.74
Lyme	3	.78
Orford	.....	.5
Do	3	.82
Piermont	3	.67
Pike	1	.49
Plymouth	.....	.7
Do	10	.89
Warren	7	.77
Woodsville	3	.63
Hillsboro County:		
Amherst	2	1.0
Antrim	7	1.01
Do	.....	.9
Bennington	3	.67
Brookline	3	.14
Deering	1	.60
Francestown	2	1.0
Goffstown	6	1.5
Greenfield	8	.79
Greenville	.....	1.2
Hillsboro	2	.65
Hudson	6	1.34
Manchester	16	1.34
Mason	1	1.0
Mount Vernon	3	1.08
Nashua	3	1.5
New Ipswich	5	1.1
Peterboro	23	.97
Weare	5	1.23
Wilton	6	1.13
Merrimack County:		
Allenstown	.....	1.5
Andover	2	.82
Boscawen	3	.88
Bradford	4	.89
Chichester	1	1.0

Chlorine determinations for Vermont—Continued.

[Parts per million.]

Source.	Samples.	Chlorine.	Source.	Samp
Windsor Co.—Cont'd.			Windsor Co.—Cont'd.	
Chester	4	0.55	Rochester	
Hartford	5	.56	Royalton	
Norwich	7	.47	Springfield	
Pomfret	1	.7	Windsor	
Plymouth	1	.6	Woodstock	

Besides these observations the following may also be co estimating the isochlors for this State:

Chlorine determinations for Vermont—Additional list.

[Parts per million.]

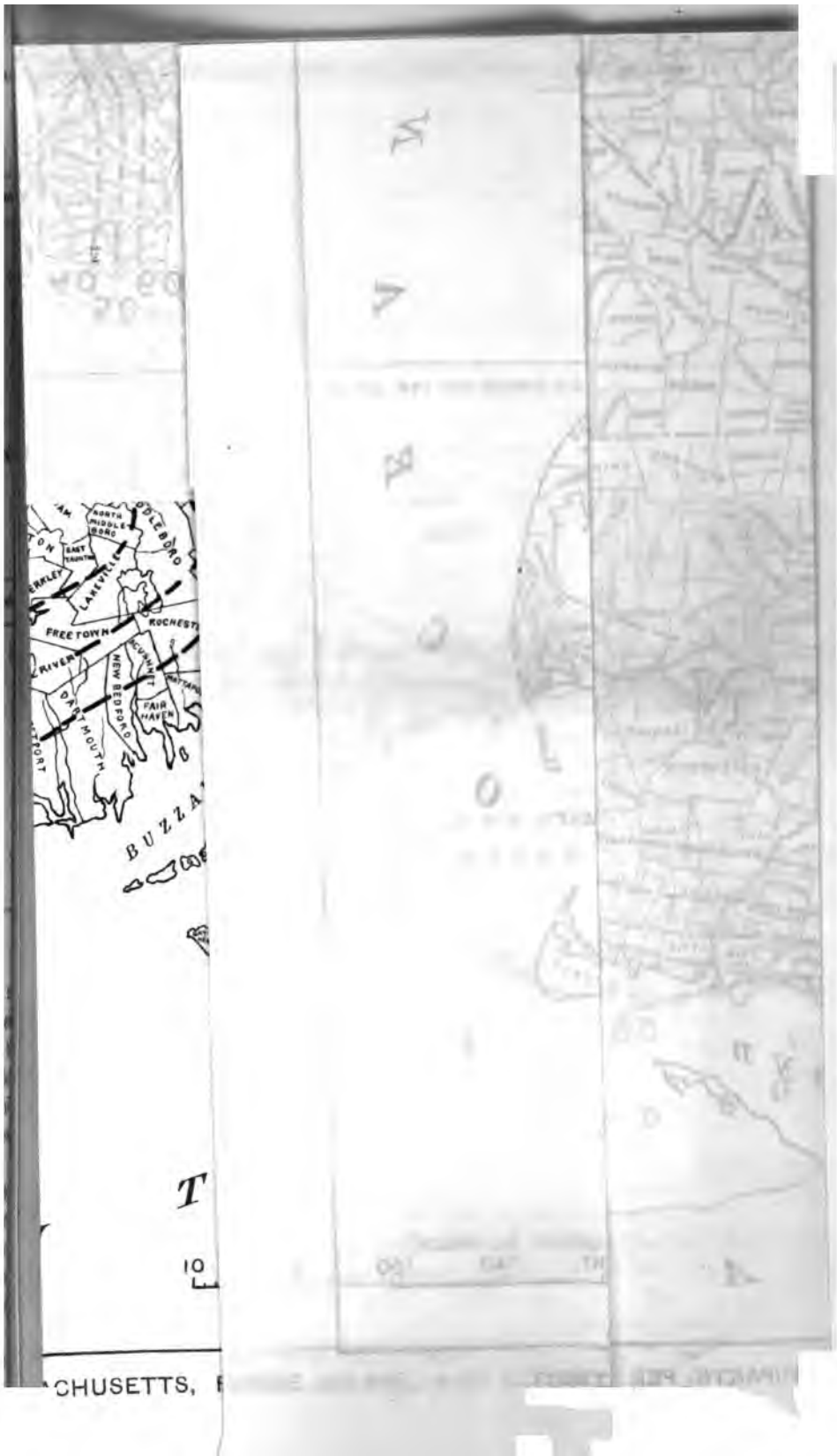
Source.	Chlorine.	Source.
Arlington, spring	0.5	Manchester, water supply
Barnet, water supply	.5	Middlesex, spring
Bennington, spring	.4	Monkton, water supply
Cambridge, spring	.4	Morrisville, spring
East Burke, spring	.5	North Troy, spring
Enosburg Falls, spring	.4	Readsboro, water supply
Georgeville, spring just above State line	.4	St. Johnsbury, Stiles Pond
Lincoln, spring	.5	Waltham, spring

THE ISOCHLORS OF MASSACHUSETTS.

The Massachusetts isochlors (Pl. IV) are practically th those published by the Massachusetts State board of hea report of 1890. In minor respects these lines have been conform with the work in adjoining States. It is only in t of 1 part per million that any material change has been m line was modified to agree with the work in Connecticu York.

The northeast winds sweeping across this State have a t drive the chlorine far inland, and it will be seen that most are farther from the coast than would be expected, and that is greatest in the most exposed areas. In the western State this is, to some extent, counteracted by the Holyoke the Berkshire Hills.

The following average observations have influenced the ment of the position of the Massachusetts isochlors: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LAKEVILLE
FREETOWN
ROCHESTER
NEW BEDFORD
DARTMOUTH
FAIR HAVEN
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CHUSETTS,

Chlorine determinations for Vermont—Continued.

[Parts per million.]

Source.	Samples.	Chlorine.	Source.	Samples.
Windsor Co.—Cont'd.			Windsor Co.—Cont'd.	
Chester	4	0.55	Rochester	4
Hartford	5	.56	Royalton	2
Norwich	7	.47	Springfield	9
Pomfret	1	.7	Windsor	4
Plymouth	1	.6	Woodstock	5

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RIVER
NEW BEDFORD
DARTMOUTH
FAIR HAVEN
BUZZA
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CHUSETTS,

Chlorine determinations for Massachusetts.

[Parts per million.]

Source.	Chlorine.
Berkshire County:	
Cheshire, reservoir	0.6
Dalton, Egypt Brook	.7
lower reservoir	.7
Great Barrington, Green River	.9
Hinsdale, east branch Housatonic River	.8
storage reservoir	.7
Lee, lower reservoir	.7
Lenox, reservoir	.7
North Adams, Notch Lake	.6
Pittsfield, Pontoosuc Lake	.4
Millbrook reservoir	.9
Sackett Brook	.8
Sheffield, spring	.7
Stockbridge, Lake Averie	.7
Williamstown, Cold Spring	.6
Sherman Spring	.5
Bristol County:	
Fall River, Watuppa Lake	5.2
New Bedford, Acushnet reservoir	5.3
Essex County:	
Andover, spring	2.4
Danvers, Middleton Pond	3.5
Haverhill, Crystal Lake	2.7
Ipswich, storage reservoir	5.3
Methuen, spring	2.0
Franklin County:	
Conway, brook	.7
Deerfield, brook	.6
Greenfield, Glen Brook	1.1
Montague, Lake Pleasant	1.0
Northfield, reservoir	.7
Orange, reservoir	.9
Whateley, West Brook	.9
Hampden County:	
Chester, Austen Brook reservoir	.6
Chicopee, Cooley Brook reservoir	1.1
Granville, middle branch Westfield River	1.2
Ludlow, Chapin Pond	1.0
Hampden County—Continued.	
Monson, well	1.2
Russell, middle branch Westfield River	.7
Springfield, Ludlow reservoir	1.2
Hampshire County:	
Huntington, east branch Westfield River	1.0
middle branch Westfield River	.9
Middlesex County:	
Ashland, Basin No. 4	2.3
Concord, Sandy Pond	2.5
Framingham, reservoir	2.3
Hudson, Gates Pond	2.0
Pepperell, spring	1.5
Sudbury, reservoir	2.2
Wayland, Snake Brook	2.3
Nantucket County:	
Nantucket, Wannacomet Pond	22.6
Plymouth County:	
Hingham, Accord Pond	6.0
Lakeville, Long Pond	4.5
Plymouth, Little South Pond	6.2
Worcester County:	
Ashburnham, storage reservoir	1.3
Berlin, Fosgate Brook	1.9
Clinton, Lyndes Brook	1.6
Holden, Tatnuck Brook	1.2
Leicester, storage reservoir	1.2
Leominster, Haynes reservoir	1.2
North Brookfield, Doan Pond	1.2
Rutland, Musquahog Lake	1.4
Southbridge, reservoir	1.3
Spencer, Shaw Pond	1.4
Sterling, Stillwater River	1.6
Worcester, Bottomly Pond	1.5
Kent reservoir	1.5
Tatnuck Brook reservoir	1.3

THE ISOCHLORS OF RHODE ISLAND.

The lines of equal chlorine for Rhode Island (Pl. IV) are drawn from data furnished by Dr. Gardner T. Swarts, secretary of the Rhode Island State board of health. Observations made in Massachusetts and Connecticut were also of great assistance in defining these lines. The following analyses in Rhode Island have influenced the determination of their position:

Chlorine determinations for Rhode Island.

[Parts per million.]

Source.	Chlorine.	Source.	Chlorine.
Kent County:		Providence County—Continued.	
Washington, Carr's pond	2.9	Harrisville, Wallum Pond	1.8
East Greenwich	4.0	Foster, spring	2.1
Newport County:		Diamond Hill, well	2.9
Block Island, Sand's pond	30.8	Washington County:	
Providence County:		Wakefield, spring	5.4
Pawtuxet Valley, reservoir	3.4	Rocky Brook	5.8
Pawtucket supply, Abbott Run	3.2	West Kingston, Barber's pond	3
Woonsocket, reservoir No. 3	2.2	100-acre Pond	3

THE ISOCHLORS OF CONNECTICUT.

The normal chlorine lines in Connecticut (Pl. IV) were established by Dr. Herbert E. Smith, chemist, Connecticut State board of health and Dr. Frederick S. Hollis, from whose article in the report of the Connecticut State board of health for 1902, together with their observations on normal waters of the State, the extract quoted below is taken.

Observations since obtained from Doctor Smith give data for adding the 4, 5, and 6 lines to the map. The strong protecting influence of Long Island cuts these lines off on the western coast in a very peculiar manner.

NORMAL DISTRIBUTION OF CHLORINE IN CONNECTICUT.

In the report of the Connecticut State board of health for 1895 a chlorine map of the State was published, which was based on averages of chlorine determinations from 38 sources. The origin of chlorine in natural waters and the value of an accurate knowledge of the normal chlorine of a district, any excess above which is an important factor in establishing the degree of contamination, were fully discussed.

During the seven years that have elapsed since the publication of the map many of the sources used in the construction of the isochlorine lines have been reexamined, and many new sources have been examined by making monthly or bimonthly analyses during one or more years. Much information has been gained also from

large number of analyses of individual samples from different parts of the State, ı the systematic examination of spring waters. The averages of the chlorine rminations from those sources which appear to be free or practically free from amination are used in the construction of the new map. The 71 sources are ded, according to the number of analyses, into three groups and entered alpha- cally. * * * Each average is entered on the map, and isochlorine lines are wn indicating the center of the comparatively limited zones in which the chlorine ies with that of the given chlorine line.

onsiderable difficulty was found, as in the case of the earlier map, in locating the s in the eastern part of the State, where there are very few public supplies and n which section but few determinations have been made. Samples were analyzed ıthly from April to September, 1902, from Wyassup Pond, in North Stonington; chdale Pond, in Voluntown; Moosup Pond, in Plainfield (the drainage area of ch extends into Killingly; the Danielson reservoirs, in Killingly, and Crystal ıd, between Eastford and Woodstock. These, with previously collected data, bably locate the lines with a fair degree of accuracy, and have resulted in lower- the 3 and 2.5 lines considerably and in raising the 2 and 1.5 lines, as compared h the earlier map.

AVERAGES OF CHLORINE DETERMINATIONS UPON WHICH THE MAP IS BASED.

[Parts per million.]

SOURCES FROM WHICH TWELVE OR MORE DETERMINATIONS HAVE BEEN MADE.

ıonia	2.8	Kent	1.6	Ridgefield	2.2
lin	1.9	Killingly	2.3	Seymour	2.3
hany	2.4	Killingworth	2.9	Southington	1.7
hel	1.9	Manchester	1.8	Do	1.9
nford	4.5	Meriden	1.9	South Manchester	1.8
dgeport	3.7	Middletown	2.5	Stamford	2.3
stol	1.5	Morris	1.6	Stonington	5.1
ıplin	1.9	Naugatuck	2.0	Thomaston	1.6
ıbury	2.3	Naugatuck River	1.6	Watertown	1.7
ham	2.7	New Canaan	2.7	Waterford	3.3
t Haven	4.1	New Milford	1.8	West Hartford	1.5
ıton	2.9	North Canaan	1.2	West Haven	6.0
mington	1.8	Norwich	2.6	Winchester	1.3
ıhen	1.5	Orange	2.3	Wolcott	1.9
enwich	3.0	Rockville	1.6	Do	2.0
nden	2.4				

SOURCES FROM WHICH SIX DETERMINATIONS HAVE BEEN MADE.

ester	3.0	Oxford	1.7	Union	1.4
tford	1.8	Do	2.2	Voluntown	2.7
osup	2.2	Stafford Springs	1.6	West Cornwall	1.1
th Stonington	3.1	Thomaston	1.6	Do	1.3

SOURCES FROM WHICH THREE DETERMINATIONS HAVE BEEN MADE.

t Granby	1.6	New Hartford	1.3	Southington	1.9
t Hartford	2.0	North Canaan	1.1	Simsbury	1.8
mington	1.9	Portland	2.4	Westbrook	6.7
swold	2.3	Plymouth	1.9	Windsor Locks	1.5
oron	2.6	Salisbury	0.9	Woodbury	1.9
v Canaan	2.7	Shelton	3.1		

Chlorine determinations for Connecticut.

[Parts per million.]

Source.	Number of samples.	Average.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Ansonia [a]	12	2.8	1897	3.40	3.25	2.80	2.75	2.64	2.45	3.20	2.30	2.30	2.65	3.00	2.9
Berlin, Kenmere reservoir (Meriden supply)	12	1.9	1899	1.70	2.40	1.90	1.30	1.70	1.60	1.90	1.70	2.00	1.60	2.40	2.30
Bethany, Dawson reservoir system [b]	40	2.4	1894	2.95	3.32	3.06	2.98	2.78	2.34	2.24	2.36	2.76	2.85	3.07	2.95
			1897	.....	.....	.....	.....	.....	.....	.....	.....	2.40	.....	.....	3.10
			1898	.....	.....	1.80	.....	.....	1.90	.....	.....	1.90	.....	.....	1.90
			1899	.....	.....	1.60	.....	.....	1.80	.....	.....	1.80	.....	.....	2.90
			1900	.....	.....	2.40	.....	.....	2.00	.....	.....	1.86	.....	.....	2.60
			1901	2.76	2.70	2.30	2.00	2.06	1.80	1.80	1.46	2.02	2.60	2.50	2.40
			1902	2.50	2.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Bethel, storage res.	12	1.9	1897	2.50	2.40	1.90	1.80	1.80	1.80	1.90	1.70	1.60	1.80	2.25	2.35
Branford	12	4.5	1900	4.60	4.00	3.50	6.30	4.40	4.50	3.90	4.62	4.10	4.34	4.70	4.90
Bridgeport (Island Brook supply)	12	3.7	1896	3.90	3.50	3.70	3.70	3.50	3.15	3.20	3.70	3.90	3.50	4.20	4.70
Bristol, storage res. and Poland River	24	1.5	1895	1.9	1.9	1.8	1.2	1.4	1.5	1.3	1.4	1.3	1.6	1.7	1.4
			1901	2.06	1.60	1.76	1.50	1.10	1.06	1.14	1.34	1.00	1.50	1.60	1.70
Chaplin, Natchaug River (Willimantic supply)	35	1.9	1889	.....	.....	.....	.....	.....	.....	.....	1.8	2.3	2.5	2.3	1.8
			1890	1.8	2.1	1.8	1.5	1.6	1.4	1.8	2.1	2.0	2.3	1.8	2.1
			1891	2.0	1.5	1.3	1.8	1.7	1.3	.....	.....	.....	.....	.....	.....
			1899	1.6	2.10	1.10	1.60	1.70	1.20	1.60	1.90	2.10	2.70	3.70	2.70
Chester, Watrous Pond [c]	6	3.0	1895	.....	.....	.....	2.9	2.8	2.9	2.8	3.1	.....	3.7	.....	.....
Danbury (Kohanza supply)	12	2.5	1896	.....	2.20	.....	3.20	.....	2.25	.....	3.30	.....	2.20	.....	2.20
			1900	3.10	.....	1.70	.....	1.80	.....	2.30	.....	2.26	.....	3.46	.....
East Lake and Padanaram reservoir	12	2.1	1896	.....	2.20	.....	2.25	.....	3.30	.....	2.50	.....	1.90	.....	1.90
			1900	2.60	.....	1.90	.....	1.90	.....	1.90	.....	1.38	.....	2.06	.....
Durham, Lake Pistepaug [d]	12	2.6	1895	3.4	2.7	2.9	2.7	2.5	2.4	2.5	2.4	2.5	2.8	2.6	2.5
Eastford, Crystal Pond [e]	6	1.8	1902	.....	.....	.....	1.94	1.84	1.74	1.60	1.80	.....	1.66	.....	.....
East Granby [f]	5	1.6	1898	.....	.....	.....	.....	1.6	1.6	1.4	.....	1.5 1.7	.....	.....	.....
East Hartford	3	2.0	1897	.....	1.90	.....	.....	.....	2.00	.....	.....	.....	.....	2.20	.....
East Haven, Lake Saltonstall (New Haven supply)	36	4.1	1890	.....	.....	.....	.....	.....	.....	.....	3.6	3.7	4.1	3.9	3.7
			1891	3.6	3.5	3.5	3.8	.....	3.7	.....	.....	.....	.....	.....	.....
			1895	.....	.....	.....	3.8	4.0	4.0	4.2	4.2	4.3	.....	.....	.....
			1897	.....	.....	.....	.....	.....	.....	.....	.....	4.10	.....	.....	4.10
			1898	.....	.....	4.40	.....	.....	4.50	.....	.....	4.20	.....	.....	4.10
			1899	.....	.....	4.00	.....	.....	4.30	.....	.....	4.20	.....	.....	4.30
			1900	.....	.....	3.90	.....	.....	4.20	.....	.....	4.80	.....	.....	4.70
			1901	.....	.....	4.74	.....	.....	4.46	.....	.....	4.66	.....	.....	4.20
			1902	4.30	4.20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Ansonia Water Company. From storage reservoir on Beaver Brook.

[b] New Haven supply. Dawson reservoir is in Woodbridge on West River, and receives water from Chamberlain reservoir on Sargent River and from Bethany reservoir, 4 miles above Dawson reservoir on West River.

[c] Situated partly in Woodstock. Samples by Dr. F. S. Smith from the source, which is a small natural lake.

[d] Wallingford public supply.

[e] Samples by Dr. H. H. Converse, of Eastford.

[f] Samples by Dr. C. M. Wooster, of Tariffville, from a small private reservoir or lake in East Granby.

Chlorine determinations for Connecticut—**Continued.**

[Parts per million.]

Source.	Number of samples.	Average.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Easton, Mill River (Bridgeport supply)	12	2.9	1896	3.05	2.40	2.20	2.85	2.70	2.60	2.60	2.90	3.00	2.80	3.45	3.55
Farmington	3	1.9	1897	.....	2.70	.....	.....	.....	.....	1.60	.....	.....	1.25	.....	.....
Hartford, reservoir No. 4	12	1.8	1898	1.84	1.60	1.60	1.90	1.80	1.80	1.70	1.70	1.80	1.60	1.90	2.30
Goshen (Torrington supply)	12	1.5	1897	1.60	1.70	1.15	1.40	1.50	1.30	1.70	1.10	1.40	1.50	2.10	2.00
Greenwich, Rockwoods Pond and Putnam Lake	36	3.0	1896	3.84	3.42	3.20	3.30	3.60	3.75	3.40	3.40	3.80	3.20	3.40	3.40
			1898	3.50	3.00	2.60	2.60	2.90	2.30	2.70	2.20	2.40	2.80	3.10	3.00
			1901	3.34	3.70	3.50	2.94	2.60	2.26	2.58	2.74	2.30	2.00	2.72	2.10
Griswold (Jewett City supply)	3	2.6	1898	3.30	.....	.....	.....	.....	2.50	.....	.....	.....	2.10	.....	.....
Hamden, Lake Wintergreen (New Haven supply)	38	2.4	1889	.....	.....	.....	.....	.....	.....	.....	2.0	2.0	2.8	3.3	2.6
			1890	3.0	3.0	3.3	2.5	2.5	2.8	2.8	.....	.....	.....	.....	.....
			1895	.....	.....	.....	2.2	2.4	2.4	2.6	2.6	2.5	.....	.....	.....
			1897	.....	.....	.....	.....	.....	.....	.....	.....	2.45	.....	.....	3.00
			1898	.....	.....	2.00	.....	.....	1.90	.....	.....	1.80	.....	.....	1.90
			1899	.....	.....	1.70	.....	.....	1.90	.....	.....	1.60	.....	.....	2.30
			1900	.....	.....	1.90	.....	.....	2.70	.....	.....	2.80	.....	.....	3.00
			1901	.....	.....	3.18	.....	.....	2.00	.....	.....	2.20	.....	.....	2.20
			1902	2.20	2.40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Hebron Spring [a]	5	2.3	1895	.....	.....	.....	.....	2.6	2.2	2.2	2.3	2.2	.....	.....	.....
Kent, reservoir	17	1.6	1894	1.7	1.4	1.4	1.5	1.5	1.4	1.2	1.4	2.2	.....	2.1	1.9
			1900	1.90	.....	1.20	.....	1.50	.....	1.90	.....	1.04	.....	1.86	.....
Killingly [b]	12	2.3	1896	.....	2.00 1.80 2.20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
			1897	2.70	2.70	2.70	.....	.....	.....	.....	.....	.....	.....	.....	.....
			1902	.....	.....	.....	2.26	2.30	2.00	2.10	2.30	2.40	.....	.....	.....
Killingworth (Clinton supply)	12	2.9	1901	3.80	3.70	3.44	2.30	2.74	2.14	2.56	3.10	2.20	3.40	2.94	3.00
Manchester:															
Storage reservoir	6	1.7	1900	1.80	.....	1.30	.....	1.60	.....	1.80	.....	1.18	.....	1.46	.....
Distributing reservoir	6		1900	1.70	.....	1.70	.....	1.80	.....	2.10	.....	1.90	.....	1.74	.....
Meriden, Merimere reservoir	35	1.9	1889	.....	.....	.....	.....	.....	.....	.....	1.5	2.0	2.0	1.8	2.0
			1890	1.8	2.0	2.4	1.9	2.3	1.8	2.0	1.8	2.1	1.9	1.8	2.0
			1891	2.1	2.1	1.9	1.5	2.4	2.1	.....	.....	.....	.....	.....	.....
			1899	1.70	1.70	1.40	1.50	1.40	1.10	1.30	1.60	1.70	1.80	1.80	1.80
Middletown, Laurel Brook reservoir	35	2.5	1889	.....	.....	.....	.....	.....	.....	.....	2.0	2.3	2.3	2.5	2.5
			1890	2.3	2.8	2.8	2.3	3.0	2.3	2.4	2.3	2.3	2.3	2.5	2.5
			1891	2.0	2.1	2.3	2.3	2.5	1.8	.....	.....	.....	.....	.....	.....
			1899	2.40	3.00	2.10	2.10	2.40	1.70	2.40	2.90	2.90	3.30	2.80	3.10
Moosup, Moosup Lake [c]	4	2.2	1902	.....	.....	.....	.....	2.50	.....	2.16	.....	2.10	2.10	.....	.....
Morris [d]	12	1.6	1901	1.78	1.60	1.50	1.70	1.56	0.96	1.46	1.58	1.90	1.50	1.90	1.42

[a] Samples by Dr. C. H. Pendleton from a natural spring in the eastern part of Hebron.
[b] Samples in 1896 collected February 26 by Mr. A. B. Prentice from the various reservoirs of the Danielson supply. Months of 1897 sample collections not given. Samples in 1902 by Mr. G. S. Brown from a tap in Danielson.
[c] Samples by Dr. W. W. Adams, of Moosup. Drainage area partly in Killingly.
[d] Branch of Naugatuck River (Waterbury supply).

Chlorine determinations for Connecticut—Continued.

[Parts per million.]

Source.	Number of samples.	Average.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Naugatuck, storage reservoir	24	2.0	1895	2.2	2.2	2.0	1.5	2.1	1.9	1.7	1.8	2.0	2.3	2.7	2.3
			1901	2.52	3.10	1.60	1.66	1.40	1.30	1.86	1.66	1.76	2.10	2.00	2.14
Naugatuck River, above Torrington	50	1.6	1893	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.8	1.4
			1894	1.4	1.7	1.3	1.2	1.3	0.9	1.5	1.4	2.0	2.0	1.6	1.5
			1895	1.7	1.6	1.8	1.6	1.5	1.6	1.3	1.6	1.7	2.0	2.3	2.1
			1896	1.80	1.65	1.40	1.30	1.65	1.55	2.20	1.90	2.30	1.65	1.50	1.80
			1897	1.30	1.40	1.30	1.20	1.30	1.20	1.40	1.10	1.40	1.50	2.00	1.80
New Canaan	3	2.7	1897	.....	3.40	.....	.....	.....	.....	2.00	.....	.....	2.70	.....	.....
Norwalk, storage reservoir	35	2.7	1894	3.5	3.0	2.6	2.6	2.4	1.8	2.2	2.2	2.4	2.9	3.3	3.1
			1897	3.45	3.40	2.90	3.00	2.70	2.80	3.00	2.50	2.50	2.60	2.90	2.70
			1900	3.00	2.20	2.70	2.40	2.20	1.90	2.00	2.50	2.46	2.74	.....	3.05
New Hartford:															
South reservoir	3	1.3	1898	.....	1.20	.....	.....	.....	1.10	.....	.....	.....	1.70	.....	.....
Stone Brook reservoir	3			.....	1.50	.....	.....	.....	1.30	.....	.....	.....	1.00	.....	.....
New Milford	12	1.8	1897	2.00	2.30	1.70	1.70	1.70	1.20	1.30	1.60	1.80	2.10	[a]2.60	2.80
North Canaan:															
Norfolk supply	3	1.1	1897	.....	1.10	.....	.....	.....	.....	1.10	.....	.....	1.05	.....	.....
Public supply	18	1.2	1894	1.5	0.9	1.2	1.0	1.4	1.2	1.0	1.1	1.3	1.3	1.4	1.6
			1900	1.20	.....	1.00	.....	1.60	.....	1.30	.....	1.00	.....	1.40	.....
North Stonington, Wyassup Pond[b]	6	3.1	1902	.....	.....	.....	3.24	2.74	3.40	2.70	3.40	3.20	.....	.....	.....
Norwich, storage res.	47	2.6	1889	.....	.....	.....	.....	.....	.....	.....	2.3	2.0	2.3	1.5	2.5
			1890	2.0	2.5	2.5	2.8	2.1	2.3	3.1	2.4	2.5	2.7	2.9	3.4
			1891	2.8	2.6	2.3	2.7	2.5	2.6	.....	.....	.....	.....	.....	.....
			1894	3.2	2.4	3.3	2.9	3.2	2.9	3.1	3.3	3.5	2.5	3.2	3.6
			1899	2.20	2.50	2.20	2.30	1.60	2.00	2.20	2.60	2.10	2.10	3.20	2.40
Orange, Maltby Lake, (New Haven supply)	20	2.3	1897	.....	.....	.....	.....	.....	.....	.....	.....	2.50	.....	.....	2.90
			1898	.....	.....	1.90	.....	.....	2.30	.....	.....	2.00	.....	.....	2.50
			1899	.....	.....	1.30	.....	.....	1.50	.....	.....	1.60	.....	.....	1.90
			1900	.....	.....	2.10	.....	.....	2.70	.....	.....	3.00	.....	.....	3.06
			1901	.....	.....	1.78	.....	.....	2.44	.....	.....	2.30	.....	.....	2.56
			1902	2.58	2.66	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oxford:															
Hatter's Spring[c]	6	1.7	1895	.....	.....	.....	1.8	1.8	1.5	1.7	1.7	1.9	.....	.....	.....
Towantic Spring[d]	5	2.2	1895	.....	.....	.....	2.2	2.5	2.0	2.1	2.0	.....	.....	.....	.....
Plainville	3	1.9	1897	.....	2.20	.....	.....	.....	.....	1.90	.....	.....	1.70	.....	.....
Plymouth (Terryville supply)	3	1.9	1897	.....	.....	2.30	.....	.....	.....	1.60	.....	.....	.....	1.70	.....
Portland	3	2.4	1897	.....	2.30	.....	.....	.....	.....	2.30	.....	.....	2.50	.....	.....
Ridgefield	12	2.24	1901	2.74	2.70	2.20	2.10	2.50	1.50	1.80	2.30	2.00	2.14	2.26	2.64
Rockville, Schenipsit Lake	23	1.6	1890	.....	.....	.....	.....	.....	.....	.....	1.7	1.5	1.5	1.8	2.6
			1891	1.8	1.1	1.3	1.8	1.5	1.8	.....	.....	.....	.....	.....	.....
			1900	1.20	1.70	1.30	1.50	1.30	1.30	1.50	1.40	1.50	1.30	1.60	1.46
Salisbury (Lakeville supply)	3	0.9	1898	.....	.80	.....	.....	.....	.70	.....	.....	.....	1.30	.....	.....

[a] Not included in average.
[b] Samples by Mr. E. H. Knowles, of North Stonington.
[c] Samples by Dr. Lewis Barnes from a natural spring located on the west side of Little River Valley, in Oxford.
[d] Samples by Dr. Lewis Barnes from a natural spring located about half a mile east of Hatter's Spring.

Chlorine determinations for Connecticut—Continued.

[Parts per million.]

Source.	Number of samples.	Average.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Seymour, Fountain Water Co. (Ansonia supply)	12	2.3	1898	2.70	2.60	2.20	2.30	2.20	2.10	2.20	2.40	2.30	2.60	1.80	2.20
Shelton	3	3.1	1897	.....	2.90	.....	.....	.....	.....	3.30	.....	.....	3.00	.....	.....
Simsbury	3	1.8	1898	.....	.....	1.30	.....	.....	2.00	.....	.....	.....	2.10	.....	.....
Southington (New Britain supply):															
Roaring Brook	12	1.7	1899	1.50	1.40	0.70	1.60	1.60	1.80	2.00	2.20	1.70	2.00	2.10	2.20
Shuttle Meadow Lake	46	1.9	1889	.....	.....	.....	.....	.....	.....	.....	1.3	1.8	2.0	1.5	1.8
			1890	2.3	2.5	2.3	2.5	2.3	2.0	2.0	1.8	2.2	1.8	1.8	1.8
			1891	1.7	1.9	1.6	2.0	2.0	1.6	.....	.....	.....	.....	.....	.....
			1894	1.9	.....	1.9	2.0	2.1	2.0	2.0	2.0	2.9	2.3	2.1	1.8
			1899	1.50	1.20	1.40	1.50	1.90	2.70	2.30	1.70	1.90	2.00	2.10	2.10
South Manchester:															
Porter reservoir	24	1.8	1900	1.40	.....	1.50	.....	1.90	.....	1.80	.....	1.90	.....	2.30	.....
Taylor storage res.			1894	2.1	1.5	1.3	1.7	1.6	1.6	2.0	2.2	1.9	2.5	2.3	2.1
			1900	1.70	.....	1.50	.....	1.50	.....	1.70	.....	1.58	.....	.....	2.10
Stafford Springs[a]	6	1.6	1900	1.60	.....	1.40	.....	1.50	.....	1.50	.....	.94	.....	2.50	.....
Stamford, Trinity Lake, N. Y.	24	2.3	1889	.....	.....	.....	.....	.....	.....	.....	1.8	.....	2.8 2.3	2.6	1.8
			1890	2.5	2.4	2.3	2.3	2.3	1.8	2.0	.....	.....	.....	.....	.....
			1899	2.10	1.50	1.50	1.60	1.90	1.60	2.00	2.70	2.70	3.20	4.00	3.10
Stonington, storage reservoir	22	5.1	1894	.....	5.8 6.0	4.4	3.1	5.4	.....	5.2	5.5	.....	5.7	7.0	6.7
			1900	5.00	4.50	4.30	4.30	4.50	3.60	4.30	3.10	4.86	5.00	5.30	5.60
Thomaston:															
Storage reservoir	35	1.6	1889	.....	.....	.....	.....	.....	.....	.....	1.0	2.0	1.8	1.8	1.3
			1890	1.8	1.8	1.4	1.9	1.3	1.1	1.5	1.7	1.7	1.5	1.5	1.8
			1891	1.6	1.3	1.2	1.6	1.4	1.3	.....	.....	.....	.....	.....	.....
			1894	2.0	2.0	2.1	1.7	1.7	1.4	1.6	1.6	1.9	1.8	2.0	2.6
Spring[b]	12	1.6	1894	1.3	1.3	1.5	1.4	1.5	1.2	1.5	1.6	1.9	1.9	2.0	2.0
Union[c]	6	1.4	1895	.....	.....	.....	1.4	1.2	1.3	1.4	1.5	1.8	.....	.....	.....
Voluntown:															
Beachdale Pond[d]	9	2.7	1902	.....	.....	.....	2.36	2.54	2.18	2.62	2.90	2.80	.....	.....	.....
Beach Pond			1896	.....	3.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Great Meadow Brook			1896	.....	3.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mt. Misery Stream			1896	.....	2.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Waterford, Lake Konomoc (New London supply)	24	3.3	1894	3.8	3.3	3.3	3.5	3.5	3.3	3.5	3.4	2.7	3.7	3.6	3.8
			1899	3.10	3.10	3.10	2.90	3.20	3.00	3.30	2.70	2.90	3.10	3.10	3.20
Watertown, Farm Brook (Waterbury supply)	35	1.7	1898	.....	1.60	1.20	1.20	1.60	1.50	1.90	1.10	1.60	2.70	1.40	1.40
			1899	1.20	1.70	1.30	1.20	1.40	.90	1.60	1.70	1.90	2.10	3.10	2.50
			1900	1.90	1.90	2.30	1.80	1.30	1.10	1.90	1.80	1.64	2.00	2.90	1.60
Westbrook[e]	5	6.7	1895	.....	.....	.....	.....	4.7	6.8	7.1	7.4	7.3	.....	.....	.....
West Cornwall:															
Lake[f]	6	1.1	1895	.....	.....	.....	.9	1.1	1.2	1.1	1.1	1.4	.....	.....	.....
Spring[g]	6	1.3	1895	.....	.....	.....	1.0	1.2	1.3	1.2	1.3	1.8	.....	.....	.....

[a] Roaring Brook; part of drainage area in Union.
[b] Samples by Dr. R. S. Goodwin from a natural spring located in the western part of Thomaston.
[c] Samples by Dr. F. L. Smith, of Stafford Springs, from a small natural lake located in the western part of Union and used as a private water supply.
[d] Samples by Rev. E. Dewhurst, of Voluntown.
[e] Samples by Dr. T. B. Bloomfield from Dies' Pond.
[f] Samples by Mr. T. S. Gold from a small natural lake.
[g] Samples by Mr. T. S. Gold from a natural spring which is used as a private supply.

Chlorine determinations for Connecticut—Continued.

[Parts per million.]

Source.	Number of samples.	Average.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	[illegible]
West Hartford:															
Reservoir No. 1...	58	1.6	1898	1.70	1.64	1.20	1.70	1.60	1.50	1.90	1.40	.....	1.20	1.80	1.[illegible]
No. 2...			1898	1.50	1.50	1.30	1.70	1.60	1.50	1.60	1.10	1.20	1.10	1.50	1.[illegible]
No. 3...			1898	1.80	1.50	1.40	1.70	1.80	1.80	2.00	1.50	1.50	1.40	1.50	1.[illegible]
No. 5...			1898	1.60	1.70	1.40	1.70	1.60	1.50	1.90	1.30	1.40	1.20	.....	1.[illegible]
No. 6...			1898	1.24	1.30	.90	1.50	1.50	1.50	1.60	1.20	1.40	1.20	1.50	1.[illegible]
W. Haven, storage res.	12	6.0	1895	6.6	6.7	6.3	5.4	5.8	5.8	4.8	6.0	4.7	6.5	6.1	6.[illegible]
Winchester, Highland Lake and Mad River (Winsted supply)	24	1.3	1895	1.9	1.9	1.9	1.4	1.4	1.5	1.4	1.4	1.4	1.5	1.3	1.[illegible]
			1901	1.56	1.30	1.36	1.22	1.24	1.10	1.12	.90	.94	.94	.90	1.1[illegible]
Windsor Locks	3	1.5	1897	.....	1.65	.....	.....	.....	.....	1.50	.....	.....	1.45	.....	.....
Wolcott, storage res. (Southington supply)	12	1.9	1894	2.5	2.1	2.0	2.0	1.8	1.5	1.4	1.6	1.7	2.0	2.4	2.3
East Mountain storage res. (Waterbury supply)	23	2.0	1889	.....	.....	.....	.....	.....	.....	.....	1.9	1.8	2.0	1.9	2.0
			1890	2.3	1.5	1.9	2.8	2.3	2.1	2.6	2.3	2.0	1.9	2.0	1.9
			1891	1.8	1.5	1.8	2.2	1.6	1.8	.....	.....	.....	.....	.....	.....
Woodbury	3	1.9	(a)	1.60	.....	.....	.....	.....	.....	1.80	.....	.....	.....	2.40	.....

a No year given.

THE ISOCHLORS OF NEW YORK.

New York produces more salt than any other State in the Union, and it would be natural to suppose that these salt deposits would affect materially a large portion of the waters in this region. Such, however, has not been found to be the case. In this State the salt beds have only a local influence, and normal waters may be found within a very narrow range of these deposits. The districts from which salt is obtained are, Ithaca, Tompkins County; Le Roy, Genesee County; Syracuse, Onondaga County; Warsaw, Wyoming County, and York, Livingston County.

In all of these districts the normal is below 0.4 part per million, and a water contaminated by salt from these deposits would in most cases be so very much higher in chlorine that it could hardly be mistaken for ordinary pollution.

The determination for the normal chlorine lines of New York State (Pl. V) is the result of analyses made by the author at Mount Prospect laboratory. The time of making analyses extended over a period of six years, and the results represent many thousand determinations of chlorine. The largest number of samples were examined on Long Island, Staten Island, and near the coast on the mainland where the differences in chlorine were greatest over a limited area. It will be seen that the Catskill and Adirondack mountains cause deflections

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toward the coast in the isochlors. This is due to the precipitation on their southern slopes of the moisture in the lower layers of the atmosphere which naturally contain the greater portion of the salt.

It will also be noted that Long Island has a remarkable effect in lowering the chlorine on the mainland. The lowest isochlor on the mainland is 3 parts per million, whereas if it were not for the protecting influence of the island it would undoubtedly be 6 parts per million. Artesian wells in Manhattan Borough have been found which have a chlorine content of as low as 2 parts per million, but these may be considered to be below normal and to consist of water from some distance north of the point from which they were drawn.

The following is a list of some of the waters which have had an influence upon the establishment of the isochlors for New York State:

Chlorine determinations for New York.

[Parts per million.]

Source.	Chlorine.
Albany County:	
Cooksburg, Catskill Creek	0.4
Delaware County:	
East Branch, reservoir	1.3
East Branch reservoir, Tonnetta Brook	1.3
Dutchess County:	
Clinton Hollow, Little Wappinger Creek	.6
Fishkill, Whalen Pond	1.0
Sprout Pond	1.0
Millerton, Wobotuck Creek	1.0
Franklin County:	
Kushaqua, Lake Kushaqua	.3
Saranac Lake, lake	.3
Saranac River	.3
Greene County:	
Ashland, Batavia Kill	.4
East Durham, Catskill Creek	.5
Prattsville, Scoharie Creek	.6
Jefferson County:	
Watertown, water supply	.3
Lewis County:	
Boyds Corner reservoir, Cold Spring Brook	1.0
Do	1.2
Livingston County:	
Sonyea, spring	0.3
New York County:	
Williamsbridge	2.2
Orange County:	
Middletown, Highland Lake	1.0
Mohegan Lake	.9
Tuxedo Park, spring	1.7
Oswego County:	
Oswego, McKenzies Pond	.3
Silver Lake	.3
Putnam County:	
Kirk Lake	1.4
Lake Gilead	1.4
Middle Branch, reservoir	1.4
Rensselaer County:	
Troy, Lake Ida	.4
Rockland County:	
Hillburn	1.4
Suffern, Mahwah River	1.4
Ramapo River	1.4
Sullivan County:	
Hasbrouck, Neversink River	.6
Liberty, spring No. 1	.6

Chlorine determinations in New York—Continued.

[Parts per million.]

Source.	Chlorine.
Sullivan County—Continued.	
Liberty, spring No. 2	0.7
No. 3	.6
Ulster County:	
Grand Hotel, station	.4
Kingston, Esopus Creek	.8
Oakes, Catskill Creek	.4
Randall Bridge, Rondout Creek	.8
Rifton, Black Creek	.6
Shokan, Esopus Creek	.5
Warren County:	
Glens Falls, Hudson River	.4
Sodom, reservoir	1.4
Westchester County:	
Croton Lake	1.5
Glen Park, pumping station	2.2
Katonah, Cross River	1.8
Kensico, reservoir	2.2
Muscoot, reservoir	1.5
Rye Pond	2.6
Tarrytown, spring	2.9
Yonkers, Grassy Sprain reservoir	2.8
Richmond County, Staten Island:	
Clifton, water supply	6.0
Richmond, Turnpike station, Crystal Water-Supply Company	6.2
Stapleton, water supply	6.0
Tottenville, water supply	6.0
Nassau County, Long Island:	
East Meadow Stream	4.6
Hempstead, well	3.0
stream at source	3.8
Massapequa, stream	4.0
Roslyn, well	4.6
Suffolk County, Long Island:	
Amagansett, well	16.5
Aqueboque, well	16.4

Source.	Chlor
Suffolk County, Long Island—Continued.	
Babylon, pond	
stream	
stream	
stream	
Sumpawampus Creek	
waterworks	
well	
Brookhaven, Connetquot River	
Bridghampton, well 1½ miles southeast of station	3
Central Islip, well	
Deer Park, well	
East Moriches, Mastic River	
Great River, Connetquot River	
Green Lawn, stream	
Greenport, well	6
Huntington, stream	
town supply	
Kings Park, stream	
Islip, Bayshore supply	
Beaver Brook	
Doxies Stream	
Orowoc Creek	
Stellenwerf Stream	
well	
Long Pond	
Melville, well	
Mellville Station, well	
Manor, stream	
well	
well	
Moriches, well	
Medford Station, well	
Mattituck, pond	1
Montauk, well	1
Northport, pond	
town supply	

Chlorine determinations in New York—Continued.

[Parts per million.]

Source.	Chlorine.	Source.	Chlorine.
uffolk County, Long Island—Continued.		Suffolk County, Long Island—Continued.	
Patchogue, pond	4.6	Sag Harbor, well	17.2
river	4.0	Sayville, Edwards Creek	6.8
Swan Creek	4.4	Patchogue supply	5.0
Tuttle Creek	5.2	Smithtown, stream	4.2
water supply	4.4	Selden, Sumpawampus Creek	4.6
well	6.1	well	5.2
Port Jefferson, town supply	4.4	Wading River, spring	10.0
Ronkonkoma, lake	4.4		

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 144.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.

2. Every member of Congress is allotted a certain number, from whom they may be obtained, free of charge, on application.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices little above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the tenth in Series L, the complete list of which follows. (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper.)

SERIES L—QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)
WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)
WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.
WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp., 15 pls.
WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.
WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.
WS 113. Strawboard and oil wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.
WS 121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.
WS 144. The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

June, 1905.

Water-Supply and Irrigation Paper No. 145 Series O, Underground Waters, 46

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS

TO THE

HYDROLOGY OF EASTERN UNITED STATES

1905

MYRON L. FULLER
GEOLOGIST IN CHARGE

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 28, 1905.

SIR: I transmit herewith, for publication as a water-supply and irrigation paper, a manuscript entitled "Contributions to the Hydrology of Eastern United States, 1905," which forms the third of a series of progress reports relating to the hydrology of the eastern portion of the country, submitted by M. L. Fuller, as geologist in charge of the eastern section of the division of hydrology. The report embraces 20 contributions by 14 geologists, and presents the results of a considerable number of subordinate lines of investigation, the descriptions of which are not of sufficient length to warrant separate publication.

The report covers a wide range of subjects and, in general, the papers form concise summaries of the subjects covered, rather than elaborate treatises. They may be grouped under five heads and include: (1) Papers dealing with special artesian problems, (2) reports describing the water resources of more or less extensive areas, (3) description of special localities, (4) papers on the water supplies of special types of deposits, and (5) descriptions of important springs.

It is believed that a composite report of this type not only reaches a much larger number of readers than any other form of publication, but puts on record a considerable amount of interesting data which, because of its brief nature, could not otherwise be made available.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

CONTRIBUTIONS TO THE HYDROLOGY OF EASTERN UNITED STATES, 1905.

MYRON L. FULLER,
Geologist in Charge.

HYDROLOGIC WORK IN EASTERN UNITED STATES AND PUBLICATIONS ON GROUND WATERS.

By MYRON L. FULLER.

WORK OF DIVISION OF HYDROLOGY.

The work of the division of hydrology deals with underground waters, or those found beneath the surface of the earth, in the same manner that the work of the division of hydrography deals with surface waters, the aim being to obtain and publish for the benefit of the people information relating to the occurrence, movements, methods of obtaining, and uses of artesian and other underground waters, including those reaching the surface both as wells and as springs

Organization.—In the earlier years of the Survey no special provision was made for the study of underground waters, although a considerable amount of information was gathered in connection with the investigation of other problems and a number of reports were published. Beginning with 1894 provision was made by Congress for the investigation of underground currents and deep wells, and from 1894 to 1902 a considerable number of special reports on underground waters were prepared under this authority. In the latter year, in order to satisfactorily meet the new demands resulting from the great increase in the use of underground waters in recent years and to develop, specialize, and systemize the work, the investigations relating to underground waters were segregated from the division of hydrography and placed in charge of a distinct organization known as the division of hydro-geology or hydrology. This division is

divided into two sections, eastern and western, the first embracing the States east of the Mississippi and those bordering that river on the west, and the second including the remaining, or the so-called "reclamation" States and Territories and Texas. The two sections have been placed in charge of geologists, Mr. N. H. Darton acting as chief of the western section and the writer as chief of the eastern.

The work of the division includes the gathering, filing, and publication of statistical information relating to the occurrence of water in artesian and other deep wells; the gathering and publication of data pertaining to springs; the investigation of the geologic occurrence, from both stratigraphic and structural standpoints, of underground waters and springs; a study of the laws governing the occurrence and flow of subterranean waters and springs, including the investigation of variations due to tidal, temperature, and barometric fluctuations; direct measurements of rate of underflow; detailed surveys of regions in which water problems are of great importance and urgency; and the publication of reports on irrigation, city water supplies, and other important uses of underground waters.

Recent work.—In connection with hydrologic investigations there has grown up a large correspondence, the handling of which makes considerable demands on the time of the members of the section. Among the notable requests received were those from the colonial secretary of Bermuda, for information as to the methods of obtaining water supply for that island; from the Peruvian Government, for the recommendation of a hydrologist to organize and take charge of a bureau of hydrology in that country similar to the hydrographic branch of the Survey; and from the secretary of the Eleventh International Congress of Hygiene and Demography, held in Berlin in 1903, for information in regard to the pollution of limestone waters.

The information requested in each case was furnished, and a member of the Survey, Mr. George I. Adams, was recommended to the Peruvian Government for the service required. Mr. Adams entered on his duties in May. Estimates for boring a deep artesian well at the American legation in Peking, China, were also obtained and submitted at the request of the Secretary of State.

In addition to answering requests from corporations and private parties in this country, the eastern section furnished information to the War Department in regard to water conditions at forts in South Carolina, Michigan, and New Hampshire, and elsewhere. In New Hampshire a special field investigation was made, with promising results. Requests for the investigation of the water supply of a number of cities and towns afflicted with typhoid epidemics were received and complied with as far as possible.

During 1904 manuscripts, including a bibliographic review and index of all publications of the United States Geological Survey

relating to underground waters, a bibliography of underground waters of the United States for 1904, and tables relating to the computation of head, flow, etc., of artesian wells were begun by Mr. Fuller. Dr. Cleveland Abbe, jr., in addition to a large amount of editorial work on manuscripts, prepared a bibliographic review of the underground-water literature of New York State.

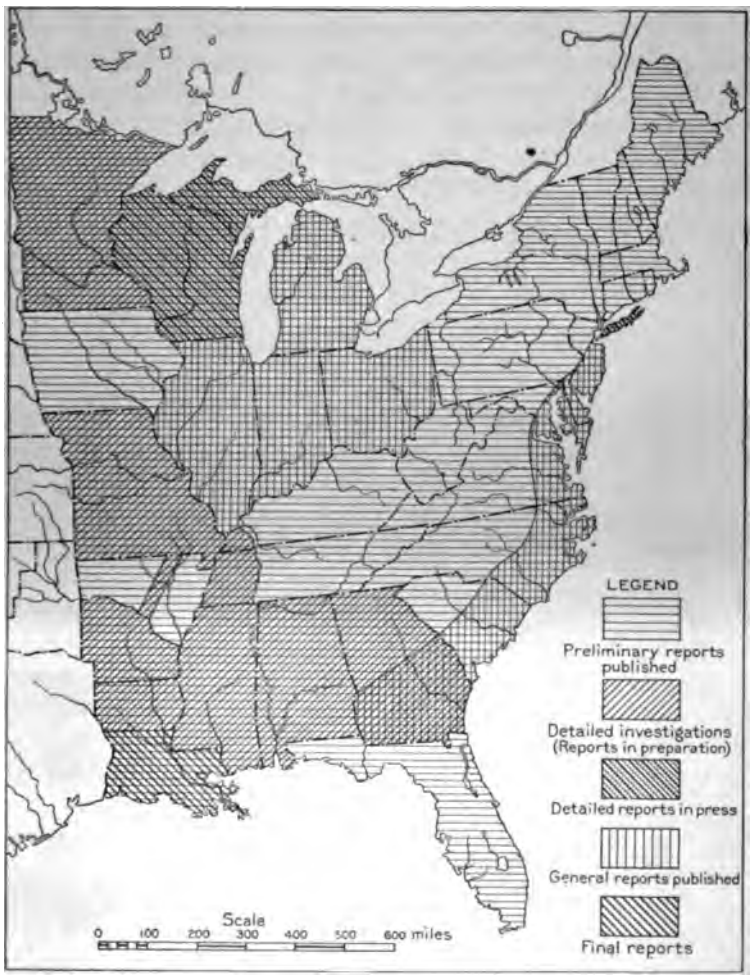

FIG. 1.—Index map showing extent of hydrologic work in eastern United States. Merely local investigations are omitted.

One of the most promising lines of work undertaken in the office is a system for collecting and preserving well records and samples from deep wells throughout the country. The plans for this work were drawn up by Mr. A. C. Veatch, who, with the assistance of Mr. E. F. Lines, inaugurated the work in July. Arrangements

have been made for procuring the effective aid of drillers, and it anticipated that a large amount of economic and stratigraphic da much of which would otherwise soon be lost, will thus be preserv It is proposed to publish the accumulated data promptly each ye making it quickly available to drillers and others interested in und ground waters.

During 1904 a paper giving a summary of legal decisions on t various phases of underground waters was prepared by Mr. D. Johnson, setting forth the general principles on which legal cisions relating to water rights are based, and giving a general i of the rights and obligations of well owners.

WORK BY STATES.

Maine.—The work in this State in 1904 consisted mainly of inv tigations relating to water-supply conditions along the shore Penobscot Bay and near Augusta, and was conducted by Mr. G. Smith in connection with surveys for the geologic branch. A sh report on the conditions at Augusta was prepared. Prof. W. Bayley also continued the collection of data by correspondei throughout the State.

New Hampshire.—The work in this State was continued under t direction of Mr. J. M. Boutwell, assistant geologist. In Mar Mr. Boutwell investigated the underground-water conditions in t vicinity of the Government forts at the mouth of Portsmouth Ha bor, the work being done in response to a request received from t Quartermaster-General. Owing to the pressure of his regular mi ing work, Mr. Boutwell was unable to continue the work in N Hampshire, and the services of Mr. G. O. Smith, geologist, we obtained to complete the investigations at Portsmouth. Both M Boutwell and Mr. Smith give favorable reports as to the possibili of obtaining underground supplies.

Massachusetts and Rhode Island.—The field work in these Stat consisted of investigations of the Pleistocene geology by Mr. M. Fuller. Cape Cod, Nantucket, Marthas Vineyard, and the Elizabe Islands, Massachusetts, and Block Island, Rhode Island, we visited and a basis for the assignment of the glacial deposits definite Pleistocene stages was established. The expense of this wo was shared with the geologic branch.

A paper on the water supply of the delta type of sand plai based on extensive observations and hundreds of borings at Clint Mass., was prepared by Prof. W. O. Crosby.

New York.—Mr. M. L. Fuller spent the month of June on Lo Gardiners, Plum, and Fishers islands, traversing the shore lir

and investigating the Pleistocene stratigraphy. The result was to substantiate the subdivisions made in 1903 and to establish a basis of correlation between the New York and New England islands. It is now possible to recognize a series of deposits and erosion intervals agreeing with those of the Mississippi-Ohio Valley. Mr. Fuller was assisted by Mr. B. L. Johnson in his work on Long Island. Mr. A. C. Veatch spent a few days in May in search of Pleistocene fossils, which were found at two new localities.

Work on the springs was continued by Mr. F. B. Weeks, geologist, who completed the field work and is now preparing a report for publication. Mr. E. M. Kindle prepared a short report on the water resources of the Catatonk area. A report on the springs of the morainal-outwash deposits near Tully, N. Y., which represent a definite class of drift waters, was prepared by Mr. G. B. Hollister.

New Jersey.—Mr. G. N. Knapp, of the State Geological Survey, has been engaged during the year on office work connected with the preparation of a detailed report on the artesian waters.

Maryland.—Arrangements were made during the year with Prof. W. B. Clark, State geologist, for cooperation in the collection of well records and samples. The collecting is done from the Maryland office and duplicates of the records and samples furnished the United States Geological Survey. Brief reports on the Pawpaw and Hancock quadrangles were prepared by Mr. George W. Stose, geologist.

Virgina.—A plan of cooperation was arranged in November with Dr. T. L. Watson, State geologist, whereby the collection of well records and data relating to water resources and springs was begun. Reports by Messrs. M. L. Fuller and T. L. Watson will be prepared at an early date.

West Virginia.—Reports of the Pawpaw and Hancock quadrangles mentioned under Maryland, and on which reports were prepared by Mr. George W. Stose, are included in this State. Mr. I. C. White, State geologist, has cooperated in the collection of well records and samples.

Georgia.—Mr. S. W. McCallie, assistant State geologist, has continued to work in cooperation with the United States Geological Survey in the investigation of artesian waters of the Coastal Plain. The large number of fossils collected by Mr. McCallie have been identified by Dr. W. H. Dall and Mr. T. W. Vaughan, resulting in an increased knowledge of Coastal Plain stratigraphy. Mr. McCallie's report on the artesian waters is nearly completed. The division of hydro-economics has largely assisted in the investigation of the composition of waters.

Alabama.—Dr. E. A. Smith, State geologist, continued cooperation with the United States Geological Survey, completing the field work

on artesian waters. His report was well under way at the end of the year. Doctor Smith has also cooperated in the collection of well records and samples.

Mississippi.—In conjunction with the geologic branch the eastern section of hydrology has continued the work on geology and underground waters. The field work, which has been in charge of Mr. E. C. Eckel, assisted by Mr. A. F. Crider, will be completed about the end of the year, and a report will be prepared at an early date, in which Mr. L. C. Johnson, who in past years has collected much data, is expected to participate.

Tennessee and Kentucky.—Mr. L. C. Glenn has continued work on a report on the artesian waters of the portion of the Mississippi embayment area included in these States, the field work on which was completed in 1903. In Kentucky Prof. C. J. Norwood, director of the State Survey, has cooperated in the collection of well records and samples.

Arkansas-Louisiana.—Mr. A. C. Veatch has been engaged during the latter part of the year in the preparation of a report on the artesian waters of southern Arkansas, northern Louisiana, and adjacent portions of Texas and Indian Territory. In the northeastern portion of the State investigations have been conducted by Prof. E. M. Shepard and Mr. M. L. Fuller on the artesian conditions of the New Madrid earthquake area. An account of the water resources of the Winslow quadrangle was prepared by Prof. A. H. Purdue.

Missouri.—In Missouri work was continued in charge of Prof. E. M. Shepard, who spent a portion of the summer in the study of the artesian waters of the State and in the investigation of the possible relation of artesian waters to certain phenomena of the New Madrid earthquake area noted under Arkansas. In this work he was accompanied part of the time by Mr. M. L. Fuller. A report on the water resources of the Joplin quadrangle was prepared by Mr. W. S. T. Smith, while notes on a number of large springs were submitted by Messrs. E. Johnson, H. F. Bain, and E. M. Shepard.

Iowa.—The work in Iowa was continued in charge of Prof. W. H. Norton, who, during the year, was consulted regarding artesian water by officials at Keokuk, Mount Pleasant, Waterloo, Fort Dodge, and Belle Plaine. A report on the artesian conditions at Waterloo was prepared. Professor Norton also assisted in the collection of well records and samples in Iowa.

Minnesota.—Prof. C. W. Hall continued work on his report on the artesian waters of the State and assisted in the collection of well records and samples.

Wisconsin.—A report on the artesian waters of Wisconsin, the field work for which was finished in 1903, was completed and submitted

by Mr. A. R. Shultz early in the year. A short report on the water resources of the Mineral Point quadrangle was prepared by Prof. U. S. Grant.

Michigan.—The work in Michigan consisted of a detailed investigation of the water supply of the drift in charge of Mr. Frank Leverett, assisted by Messrs. C. A. Davis, W. M. Gregory, Isaiah Bowman, and Jon Andreas Udden. Mr. M. L. Fuller, chief of section, made a special investigation of the failure of wells in the Carleton district, southwest of Detroit, visited about twenty flowing-well areas in the western portion of the State, and spent some time in the field with the various parties. Reports on the Carleton and western Michigan artesian districts were prepared before the close of the year. Dr. A. C. Lane, State geologist, cooperated in the saving of samples and Mr. R. E. Horton prepared a report of the drainage of wells into swamps.

SUMMARY OF REPORT.

In the following paragraphs the aim has been to present a concise summary of the various short papers embodied in the present report and to call attention to those features deemed of special interest or importance.

Drainage of Ponds into Drilled Wells, by Robert E. Horton.

In the deeply drift-covered regions of Michigan and adjoining States the surface is characterized by numerous ponds held in the basin-like depressions known as "kettles." These are often shallow, and if drained would leave in some cases many areas of rich farming lands. Their situation in depressions is such that they can seldom be drained by ditches, but attempts to draw off the water by wells have been more successful. The average cost of a 3-inch well, including casing, should not exceed $1 a foot, and in most cases a depth of 100 feet will be sufficient. The wells are sunk with the mouths below water level and on completion are provided with a bell mouth and surrounded by screens. The effectiveness of the wells depend upon the height to which the underground water will rise being less than that of the pond. Under such conditions the water enters the well mouth and passes down the pipe and out into the porous sand, gravel, sandstone, etc., at the bottom, or into fissures where the well ends in compact rock. The construction of the wells, their capacity for drainage, etc., are described in detail in the paper. A considerable number of wells which have been successful in the reclamation of lands formerly covered by ponds are cited.

Two Unusual Types of Artesian Flow, by Myron L. Fuller.

The first of the two unusual types of flow described is from practically uniform sand, the impervious confining cover usually assumed to

be essential to flows being absent. It appears, from observations on Long Island, New York, and in Michigan, that while any layer slightly finer than the water bed may, even though permeable, serve as a confining bed, such a layer is not necessary, an overlapping arrangement of slightly elongated grains in a uniform sand being apparently sufficient to produce the resistance to upward movement essential to artesian flows. The second unusual type of flow described is from the jointed upper portion of limestone and other rocks in southeastern Michigan. Although the waters are rock waters in composition, their origin and head are shown to depend on drift deposits, which likewise serve as the confining stratum. In fact, in all essentials they are drift waters, the rock simply serving as a carrier in place of the layer of stratified sand or gravel commonly present. The mineral matter is dissolved from the rock during the passage of the water through it.

Construction of the so-called Fountain and Geyser Springs, by Myron L. Fuller.

The term "fountain spring" is used to designate a spring whose water is made to rise to a point above the surface of the ground at the spring, while by a "geyser spring" is meant one so piped that a jet is intermittently thrown to a greater or less height. The classes of natural springs, the conditions under which they may be converted into one or the other of the artificial types mentioned, and the simple methods of construction employed are described and illustrated.

A Convenient Gage for Determining Low Artesian Heads, by Myron L. Fuller.

In this paper the difficulties in determining flows with the ordinary cumbersome gages, requiring considerable material, much time, and some skill, are pointed out, and attention is called to the necessity of a more convenient form for rapid work. The requirements were finally filled by a 2-inch nickel-plated gage, which can readily be carried in the vest pocket and which can be used for all pressures up to 50 pounds. By means of a rubber tube opening out into a flange, which is held firmly against the discharge pipe of the well, the pressure can be instantly obtained.

Water Resources of the Catatonk area, New York, by E. M. Kindle.

The Catatonk area lies in the hilly region northwest of Binghamton, between that city and the Finger Lakes region. The rocks are Devonian in age and are nearly flat, though showing very low swells, extending in an east-west direction. The whole region is more or less covered with glacial drift. As a whole the rocks are compact and carry little water, although they afford numerous small springs. Flows, however, are yielded by the sands and gravels at

aca, near Slaterville Springs, west of Brookton, at Newark Valley, l just north of Tioga Center. Some of the water is high in ıeral matter and possesses medicinal properties, which at Slater- e Springs have led to the development of a resort. Of the mineral ings may be mentioned the Dryden, Speedsville, Nanticoke, Spen- , Halsey, Valley, Glen Cairn, and springs south of Owego. The ters are commonly of the sulphur type, in which instances they bably come from the rock, and are sometimes of medicinal value. several of the springs sulphur is deposited by the water. A num- of summer hotels have been built. The streams are ordinarily rly pure, one having long afforded the water supply for Ithaca, ile Fall Creek supplies power for three or four mills and factories Ithaca and the hydraulic laboratory, etc., of Cornell University.

Water Resources of the Pawpaw and Hancock Quadrangles, West Virginia, ryland, and Pennsylvania, by George W. Stose and George C. Martin.

The area treated in this paper lies at the northernmost bend of the tomac and is a moderately hilly region, with occasional high north- t-southwest ridges, rising to 2,260 feet in Cacapon Mountain. The ks consist of quartzite, sandstone, shale, and limestone, from dovician to Carboniferous in age. A number of streams besides Potomac have considerable volume and fall and afford present prospective water powers. Springs are numerous, among the st important of which are those at Berkeley Springs, W. Va., site of a fashionable resort. The water issues from steeply lined sandstone at a number of points, has a temperature of 73° F., d yields about 1,500 gallons per minute. The water carries the all amount of 13 grains of mineral matter per gallon, mainly bonate of lime.

Water Resources of the Nicholas Quadrangle, West Virginia, by George H. ıley.

The area treated includes about 1,000 square miles in central West rginia, a little east of New and Kanawha rivers. The region is remely hilly, the crests often standing 500 to 1,000 feet above the jacent streams and reaching a maximum height of nearly 4,400 feet. e tributaries from the north entering Gauley River (which crosses area from east to west near the center) occupy broad, flat valleys arated from each other by irregular divides. There is some farm- along the bottoms of these tributaries, but over the remainder of area the valleys are sharp and steep and unsuited for cultivation. e rocks are mainly sandstones and sandy shales of the Pottsville oup, and include some valuable coals and clays. The dip averages m 100 to 200 feet per mile to the northwest. The domestic water pply of the uplands is usually obtained from shallow wells, which

often go dry in time of drought, necessitating recourse to the springs issuing along the coals, etc., at points lower down in the valleys. Wells in the valley bottoms generally obtain better supplies, the town supplies of Summersville and Richwood being from such wells. The water throughout the area is of the soft "freestone" type. The geologic structure would seem to afford unusually favorable conditions for artesian waters. The region is forested, giving flows to the streams throughout the year, and, owing to the character of the valleys, the opportunities for the construction of dams for power purposes are unusually good.

Water Resources of the Mineral Point Quadrangle, Wisconsin, by U. S. Grant.

This quadrangle is situated mainly in southwestern Wisconsin, the Illinois State line barely falling within its limits. Although a rich agricultural country, it is situated in the heart of the upper Mississippi Valley lead and zinc region and produces much ore. The topography is that of a low plateau, above which rise a few isolated elevations and below which are the wide flat-bottomed valleys occupied by the streams. The rocks consist of Paleozoic limestone shales and sandstones. The lead and zinc deposits occur at the base of the Trenton and at the top of the underlying Platteville limestone. Springs are numerous in the area, occurring mainly at the bottoms of the Galena and Platteville limestones and the St. Peter sandstone. They are often used for domestic and dairy purposes. The streams were formerly a source of many small water powers, but are now rarely utilized. Wells are commonly of the drilled type and generally vary from a depth of 10 feet in the valleys to 100 feet in the uplands. The largest supplies are from the St. Peter sandstone, but the Galena furnishes much water of good quality for domestic purposes. Deep wells are sunk to the St. Peter, when it is below the surface, and to the Potsdam, from both of which abundant supplies are generally obtained by pumping, although neither furnishes a flow. The Potsdam water is more highly mineralized than that from the higher horizons.

Water Resources of the Joplin District, Missouri Kansas, by W. S. Tangier Smith.

This district lies at the intersection of the boundary lines of Missouri, Indian Territory, and Kansas, and includes the famous Joplin lead and zinc region. Topographically it lies on the western outskirts of the Ozark region and consists of level plains cut by valleys to a maximum depth of 200 feet. The drainage is southward into Arkansas River. The surface rocks are mainly limestones of the cherty lead- and zinc-bearing formation known as the Boone, but some shales and sandstones of the Cherokee formation occur. The dip is low to the northwest. The rocks are characterized by open folding, with considerable faulting in the vicinity of the ore deposits. The

ıms, which are all spring fed, afford power at a number of points, Spring River and Center and Shoal creeks furnish water supplies most of the cities in the district, including Joplin, Webb City, :hage, and Galena. Other streams, formerly yielding good water, now polluted by mine waters. Springs are common, sometimes of e volume, and are used for domestic or mine supplies. A part of waters are high in mineral matter, sometimes carrying an apprele quantity of zinc, and give rise to soft white, cream-colored, or lish deposits. The wells in the region are usually shallow, but in mining district there are several thousands of deep test borings : in search of ore, some of which are used as wells. No flows have obtained, although supplies ranging up to 12,500 gallons per · are obtained by pumping or air lift. A considerable number of yses of waters from streams, springs, and wells, some of which are ›nsiderable detail, are given.

ater Resources of the Winslow Quadrangle, Arkansas, by A. H. Purdue.

his quadrangle lies mainly in western Arkansas, a little north .rkansas River, but includes a few square miles of Indian Terri-. The topography is that of a plateau deeply cut by streams l it presents a mountainous landscape, forming a part of what is vn as the "Boston Mountains." The rocks consist of limestones, :s, and sandstones of Carboniferous age, four of which—the ıe chert (largely limestone), Pitkin limestone, and the sandstones ıe Hale and Winslow formations—are important water-bearing ıations, yielding abundant water to wells or springs. The water :s from soft in the case of the Winslow formation to medium ıe Boone chert and Hale formation and hard in the Pitkin lime-:. Some of the springs yield water highly mineralized, and in or two cases are utilized for medicinal purposes, or as resorts. e of the water could be used to advantage for power or irrigation ›oses.

ter Resources of the Contact Region between the Paleozoic and Mississippi ıyment Deposits in Northern Arkansas, by A. H. Purdue.

ıis paper treats of the geology and water resources of a belt ı 12 to 15 miles wide, extending along the western edge of the issippi embayment deposits from Arkansas River northward to Missouri line. The geology of both the Paleozoic and embayment :, including a description of the beds and their history, are con-ed in some detail, and a geologic map showing the boundary greater accuracy than any previously published map is given. meaning of ground water, the relative amounts of run-off and nd water, the character of the water table, and the essential acteristics of a water-bearing formation are discussed, and the r-bearing beds, including the Ordovician limestone, Boone chert,

Batesville sandstone, Pitkin limestone, Coal Measures, and the soft embayment deposits are described. Other subjects considered are the source of water from rainfall and leakage from streams and Paleozoic rocks, the amount, composition, and uses of the water, the prospects for flowing wells, and the problems of type, location, depth, and construction of wells from the sanitary standpoint. The practical discussions of these questions of general interest should prove of substantial benefit to the residents of the Arkansas lowlands.

Water Resources of the Portsmouth-York Region, New Hampshire and Maine, by George Otis Smith.

The examination of the water resources in the vicinity of Portsmouth was undertaken at the request of the War Department, with a view of determining the available supplies for the several forts at the mouth of the harbor. The conditions proved to be typical of those existing in districts of similar rocks at points along the Maine coast, where the problem of obtaining deep-well waters for the use of summer residents, especially those living on small islands, is one of great importance. The city supply of Portsmouth is from shallow wells in loose surface deposits, from which the farm supplies in the region are also generally obtained. Another source, utilized at the navy-yard, is the ponds on the slope of Mount Agamenticus, while a third source is the deep-rock wells. These rock wells, which supply a number of hotels and summer residences, have in numerous instances been successful in obtaining good supplies, the waters sometimes even flowing at the surface, demonstrating the existence of artesian storage of a type quite different from that usually described. The rocks consist mainly of schists, slates, and quartzites, which are compact, upturned, and characterized by numerous joints. Some dikes of igneous rocks occur. The water is contained in bedding planes, joint openings, etc., through which it circulates slowly, its escape to the surface being prevented by the closing of the joints by mineral deposits near the top. The water is to be regarded as coming from distant rather than adjacent areas. In many cases abundant supplies are obtained at less than 100 feet, while wells of 300 feet are nearly always successful, although, owing to the lack of regularity in the occurrence of joints, an occasional failure results. The schist appears to be the most promising rock.

A Ground-Water Problem in Southeastern Michigan, by Myron L. Fuller.

The spring and summer of 1904 were marked by a pronounced shortage of water in certain areas in southeastern Michigan, the failure of the wells being commonly attributed to underdrainage of a powerful flowing well on Grosse Isle, a few miles away. Investigation showed the loss of water to be due not to the big flowing well, nor to the deep quarry at Newport, but to certain general causes appli-

cable to many other regions throughout the country. Of these causes deforesting seems to have been one of the most important factors in the decrease of supplies in the past, but had little immediate connection with the present shortage, which seemed to be due (1) to the extensive ditching that the region has undergone, which has lessened the amount of water absorbed by the ground; (2) to the early frost of 1903, which prevented the autumn and winter rains from entering the ground, and (3) to the drought during the spring and summer of 1904, during which little or no rain fell for long periods. The water will probably return only after one or more wet years, and may possibly never return in its original amount, but a deepening of the wells will probably result in securing supplies adequate for the ordinary needs of the inhabitants. The condition of the wells during 1904 is described at some length, and the application to other regions of the conclusions regarding the shortage is discussed.

Water Supplies at Waterloo, Iowa, by W. H. Norton.

The investigation of the conditions at Waterloo was undertaken in response to requests from city officials with a view of determining the availability of artesian waters to replace the surface supply from Cedar River, which had become dangerously polluted, giving rise to a severe typhoid epidemic. The investigation showed that shallow ground water was slight in amount, owing to its ready drainage into Cedar River and its extensive absorption by the underlying rock. There are, however, strong springs issuing from the limestone 5 or 6 miles up the valley, and artesian water could probably be found in the St. Peter sandstone at about 850 feet, the Jordan sandstone at about 1,300 feet, and the basal (Potsdam) sandstone at 1,800 feet or more. Such deep-seated water would be perfectly healthy, but would probably give more or less trouble in boilers on account of scale-forming minerals in solution. Two or more wells would be necessary to furnish the 3,000,000 gallons daily which the city requires. The necessity of test wells, the question of supplementary supplies, the head of the artesian waters, and the question of permanency of flow are all discussed.

Water Supply from Glacial Gravels near Augusta, Me., by George Otis Smith.

The region treated in this paper includes the Silver Lake system of ponds, about 5½ miles northwest of Augusta, which it was proposed to utilize, in connection with a series of springs at the head of Spring Brook, as a source of a water supply for that city. There are 13 ponds, with an aggregate area of 215 acres, connected in part by sluggish streams, but without any outlet stream. The springs mentioned are half a mile south of the southernmost pond. A study of the area

shows that the gravels probably occupy a sort of basin, bounded beneath the surface, both on the east and west, by rock or impervious till. The drainage basin is divided on the surface by a winding ridge which separates the ponds into two chains. The water level in the ponds in general shows a regular decrease to the south, but the rate differs in the two chains, making it apparent that the water level of the ponds depends on the height of the ground-water tables, of which there are two—one on each side of the medial ridge. The movement of the water is manifestly to the south, its point of issue being in the springs at the head of Spring Brook, the flow of which is supplied from the same ground-water sheet as that which supplies the ponds, which are merely the visible portions of the ground-water lake. Since the ground-water body occupies a confined basin, any water taken from the ponds diminishes by so much the total amount, involving a corresponding decrease in the yield of the springs, which constitute practically the only source of outflow from the basin. Hence, the city supply would not be increased by drawing from the ponds.

Water Supply from the Delta Type of Sand Plain, by W. O. Crosby.

During the construction of the water system for Boston and the metropolitan district of Massachusetts the structure and waters of the sand plains near Clinton were thoroughly investigated by means of many hundred borings, and a summary of the results is presented in the present paper as an example of a type of water supplies of importance throughout New England. The plains, of which there are several, were deposited as deltas in a glacial lake caused by the obstruction of the northward-flowing Nashua River by the retreating ice sheet of the last Glacial epoch. The deposits known as the North Dike Plain are particularly considered, and their topography, composition, structure, origin, and water supplies are described, together with the crests and valleys of the buried rock surface upon which they lie. The form of the water table and the phenomena of "lost water" (water passing off into the sands at points below the water table), as well as the occurrence of "springs" or water seams under artesian head, are discussed. The deposition of iron and the cementing of the materials in certain of the beds and the oxidation of the drift, both of which features are dependent on the circulating waters, are also described and explained. A summary of the conditions and their application to other localities concludes the paper.

Waters of a Gravel-Filled Valley near Tully, N. Y., by George B. Hollister.

In a valley near Tully, N. Y., there is a thick accumulation of sands and gravels, representing the accumulations taking place at the termination of a tongue of glacial ice which occupied the valley during

a late geological period. The deposits are similar to those at many other points in New York and New England, and the water-supply conditions represent a type of importance in these regions. The paper describes the character of materials, the volume of the springs issuing from them, the deposits of tufa formed by the spring waters, the waters of the lakes occurring in depressions in the gravels, and the composition of the spring and lake waters. A considerable number of analyses are given.

Notes on Certain Hot Springs of the Southern United States, by Walter Harvey Weed.

Although the economic importance of the hot springs of our country as resorts is immense there is a dearth of reliable information as to their occurrence. In this paper descriptions of two of the more important localities, the Warm Springs of Georgia and the Hot Springs of Arkansas, are described in some detail. The former issue from a fracture near the base of Pine Mountain, a sandstone ridge rising from the Piedmont Plateau, about 85 miles south-southwest of Atlanta. The waters, which, judging from their temperature of 87°, come from a depth of about 1,600 feet, are very pure, agreeing in this respect with the water of the Hot Springs of Arkansas. These latter springs issue from vents in old tufa or hot-spring deposits in a valley in a somewhat mountainous region of strongly folded Carboniferous and lower Silurian rocks about 50 miles west of Little Rock. The springs are Government property, and about them have been developed parks, numerous bathing establishments, and hotels, making the most important hot-spring resort in America and one comparable with the great European spas. The paper gives an account of the history, topography, geology, flow, temperature, and composition, including many analyses, of the springs. The discharge varies from about 500 gallons per twenty-four hours in the smallest spring to 201,000 gallons in the largest, and the temperature from 46° to 147°. The waters contain some carbon dioxid, nitrogen, and oxygen, the latter two resulting from the absorption of air, and in general correspond closely to the ordinary mountain springs, except in the element of heat, which is supposed to be derived from heated vapors rising from deep-seated igneous intrusions. There seems to have been little, if any, decrease in temperature or volume since about 1850, when the springs were first carefully studied.

Notes on Certain Large Springs of the Ozark Region, Missouri and Arkansas, compiled by Myron L. Fuller.

In this paper are put on record data relating to some of the immense springs of the Ozark Mountains which have recently been investigated by members of the Geological Survey with the object of determining their availability for water power. Those discussed are Greer,

Van Buren, Fanchon, Alley, Blue, Mesamer, and Boiling springs in Missouri, and Mammoth Spring in Arkansas. All occur in limestone rocks, and several represent the outlets of subterranean rivers, while one, the Blue Spring, issues from a natural well nearly 50 feet in depth. The waters, though sometimes somewhat roily after storms, are usually entirely clear, of a bluish tinge, and pure except for the dissolved lime and magnesia. The summer temperatures average about 56°. Measurements in 1904, when the springs appear to have been very low, as compared with some past years, showed the flow to range from 23 cubic feet per second at Blue Spring up to 265 second-feet at Greer Spring. In nearly every instance the springs either furnished power or could be made to do so. Some of the springs show an intermittent flow, as, for instance, one near the junction of Jacks Fork and Current River, Shannon County, Mo., which has a rhythmic discharge with maxima about forty minutes apart, with intervening minima, when the flow nearly ceases. Sink holes are numerous, and in places are thought to mark the position of the underground streams feeding the springs.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

The results of the work of the Survey on underground waters and springs are published in a number of different forms, briefly described below. Complete lists of Survey publications, with prices of such of them as are for sale, can be obtained on application to the Director.

1. Papers and reports accompanying the Annual Report of the Director: Prior to 1902 many reports relating to underground waters were published in the royal octavo cloth-bound volumes, which accompanied the annual reports of the Director. This form of publication for scientific papers has been discontinued and a new series, known as Professional Papers, has been substituted.

2. Bulletins: The bulletins of the Survey comprise a series of paper-covered octavo volumes which in general contain a single report or paper. These bulletins formerly sold at nominal prices, but are now distributed free of charge to those interested in the special subject discussed. This form of publication is used for presenting information relating to underground waters when the hydrologic descriptions are accompanied by extended topographic or geologic discussions. Before the inauguration of the Water Supply and Irrigation series of papers the bulletins were the form of publication for all shorter papers related to water supplies. Their small size precludes the use of large maps or plates, and reports requiring large illustrations are therefore issued in the series of Professional Papers.

3. Professional Papers: This series, paper covered, but quarto in size, is intended to include such papers as require large maps or other illustrations. Their publication was begun in 1902, and they are distributed in the same manner as the bulletins.

4. Monographs: This series consists of cloth-bound quarto volumes, and is designed to include exhaustive treatises on any subject coming within the province of the Survey. As yet no paper relating to water supply in any of its forms has been published as a monograph. The volumes of this series are sold at cost of publication.

5. Geologic Folios: Under the plan adopted for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and these quadrangles, which number several thousand, are separately surveyed and mapped. The description of each quadrangle is issued in the form of a folio as the survey is finished. When the series is complete the folios will constitute a Geologic Atlas of the United States. Copies of the folios, like the preceding publications, are sent to a large number of public institutions and libraries. Those remaining are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Many of the folios contain special descriptions and elaborate maps showing the occurrence of underground waters.

7. Reports on Mineral Resources: The reports of this series are cloth-bound octavo volumes, published annually, giving statistical summaries of the output of the various mineral products, including mineral waters and brines. They were issued as a distinct series from 1882 to 1893. They were then made a part of the Annual Report until 1900, when their separate publication was resumed. The volumes of the earlier series were generally sold at about 50 cents, but the later ones are for free distribution.

8. Water-Supply and Irrigation Papers: These are of octavo size, and are published in red paper covers. They are distributed gratuitously. As the name indicates, only papers relating to investigations and problems of water supplies in their various forms are published in this series. In common with the professional papers and bulletins the water-supply papers are divided into a number of series, as follows:

(I) Irrigation.
(J) Water storage.
(K) Pumping water.
(L) Quality of water.
(M) General hydrographic investigations.
(N) Water power.
(O) Underground waters.
(P) Hydrographic progress reports.

9. Reclamation Service Reports: These reports are octavo volumes, bound in light olive-green cloth, and issued annually. They cover the engineering and construction work relating to projects for reclaiming the arid public lands. In the three reports issued so far nothing relating to underground waters is given.

In addition to the various series of reports mentioned, the Survey issues a large number of topographic and other maps, on some of which springs are shown, as well as sinks resulting from subterranean drainage. Lists of the maps may be had on application.

The following detailed lists contain all papers on underground waters and springs issued by the Survey:[a]

PAPERS IN ANNUAL REPORTS.

The requisite and qualifying conditions of artesian wells, by T. C. Chamberlin: Fifth Ann. Rept., 1883–84, pp. 125–173, 1 pl.

Formation of travertine and siliceous sinter by the vegetation of hot springs, by W. H. Weed: Ninth Ann. Rept., 1887–88, pp. 613–676, 10 pls.

The potable waters of eastern United States, by W J McGee: Fourteenth Ann. Rept., 1892–93, pt. 2, pp. 1–47.

Natural mineral waters of the United States, by A. C. Peale: Fourteenth Ann. Rept., 1892–93, pt. 2, pp. 49–88.

Water resources of a portion of the Great Plains, by Robert Hay: Sixteenth Ann. Rept., 1894–95, pt. 2, pp. 535–588, 3 pls.

The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 551–601, 15 pls.

Preliminary report on artesian waters of a portion of the Dakotas, by N. H Darton: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 603–694, 39 pls.

The water resources of Illinois, by Frank Leverett: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 695–849, 11 pls.

Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with reference to the occurrence of underground waters, by R. T. Hill and T. W. Vaughan: Eighteenth Ann. Rept., 1896–97, pt. 2, pp. 193–321, 44 pls.

Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept., 1896–97, pt. 4, pp. 419–559, 5 pls.

New developments in well boring and irrigation in eastern South Dakota, 1896, by N. H. Darton: Eighteenth Ann. Rept., 1896–97, pt. 4, pp. 561–615, 10 pls.

Principles and conditions of the movements of ground water, by F. H. King: Nineteenth Ann. Rept., 1897–98, pt. 2, pp. 59–294, 11 pls.

Theoretical investigation of the motion of ground waters, by C. S. Slichter: Nineteenth Ann. Rept., 1897–98, pt. 2, pp. 295–384, 1 pl.

The rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept., 1897–98, pt. 4, pp. 633–717, 3 pls.

Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton: Nineteenth Ann. Rept., 1897–98, pt. 4, pp. 719–785, 45 pls.

[a] For publications appearing since this text was prepared, see outside of back cover.

Preliminary description of the geology and water resources of the southern half of the Black Hills and the adjoining regions in South Dakota and Wyoming, by N. H. Darton: Twenty-first Ann. Rept., 1899–1900, pt. 4, pp. 489–599, 55 pls.

The High Plains and their utilization, by W. D. Johnson: Twenty-first Ann. Rept., 1899–1900, pt. 4, pp. 601–741, 44 pls., and Twenty-second Ann. Rept., 1901–2, pt. 4, pp. 631–669, 15 pls.

Geography and geology of the Black and Grand prairies, Texas, with detailed descriptions of the Cretaceous formations and special reference to artesian waters, by R. T. Hill: Twenty-first Ann. Rept., 1899–1900, pt. 7, 666 pp., 71 pls.

Mineral waters, by A. C. Peale: Sixteenth Ann. Rept., 1894–95, pt. 4, pp. 707–721; Seventeenth Ann. Rept., 1895–96, pt. 3 (continued), pp. 1025–1044; Eighteenth Ann. Rept., 1896–97, pt. 5 (continued), pp. 1369–1389; Nineteenth Ann. Rept., 1897–98, pt. 6 (continued), pp. 659–680; Twentieth Ann. Rept., 1898–99, pt. 6 (continued), pp. 747–769; Twenty-first Ann. Rept., 1899–1900, pt. 6 (continued), pp. 597–622.

BULLETINS.

32. Lists and analyses of the mineral springs of the United States; a preliminary study, by A. C. Peale. 1886. 235 pp.
47. Analyses of waters of the Yellowstone National Park, with an account of the methods of analysis employed, by F. A. Gooch and J. E. Whitfield. 1888. 84 pp.
131. Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell. 1895. 126 pp.
138. Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton. 1896. 232 pp., 19 pls.
199. Geology and water resources of the Snake River Plain of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

PROFESSIONAL PAPERS.

17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
32. Geology and underground water resources of the Central Great Plains, by N. H. Darton. 1904.

REPORTS ON MINERAL RESOURCES OF THE UNITED STATES.

Mineral waters, by A. C. Peale: Mineral Resources of the United States, 1883–84, pp. 978–987; 1885, pp. 536–543; 1886, pp. 715–721; 1887, pp. 680–687; 1888, pp. 623–630; 1889–90, pp. 521–535; 1891, pp. 601–610; 1892, pp. 823–834; 1893, pp. 772–794; 1900, pp. 899–905; 1901, pp. 961–966; 1902, pp. 993–1002; 1903, pp. 1137–1162.

WATER-SUPPLY AND IRRIGATION PAPERS.

4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls.
6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls.
12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls.
21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp.
30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls.
34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
53. Geology and water resources of Nez Perces County, Idaho, pt. 1, by I. C. Russell. 1901. 86 pp., 10 pls.
54. Geology and water resources of Nez Perces County, Idaho, pt. 2, by I. C. Russell. 1901. 87-141 pp.
55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 63 pp., 7 pls.
57. Preliminary list of deep borings in United States, pt. 1, by N. H. Darton. 1902. 60 pp.
59. Development and application of water in southern California, pt. 1, by J. B. Lippincott. 1902. 95 pp., 11 pls.
60. Development and application of water in southern California, pt. 2, by J. B. Lippincott. 1902. pp. 96-140.
61. Preliminary list of deep borings in United States, pt. 2, by N. H. Darton. 1902. 67 pp.
67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls.
77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.
78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.
90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.
101. Underground waters of southern Louisiana, by G. D. Harris; with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.
102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.
110. Contributions to hydrology of eastern United States, 1904, M. L. Fuller, geologist in charge. 1905. 211 pp., 5 pls.
111. Preliminary report on underground waters of Washington, by Henry Landes. 1905. 85 pp., 1 pl.

112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1905. 55 pp., 7 pls.
114. Underground waters of eastern United States, M. L. Fuller, geologist in charge. 1905. 285 pp., 18 pls.

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13. Fredericksburg folio, Maryland-Virginia, by N. H. Darton.
23. Nomini folio, Maryland-Virginia, by N. H. Darton.
36. Pueblo folio, Colorado, by G. K. Gilbert.
42. Nueces folio, Texas, by R. T. Hill and T. W. Vaughan.
67. Danville folio, Illinois-Indiana, by M. R. Campbell and Frank Leverett.
68. Walsenburg folio, Colorado, by R. C. Hills.
70. Washington folio, District of Columbia-Virginia-Maryland, by N. H. Darton and Arthur Keith.
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80. Norfolk folio, Virginia-North Carolina, by N. H. Darton.
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85. Oelrichs folio, South Dakota-Nebraska, by N. H. Darton.
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99. Mitchell folio, South Dakota, by J. E. Todd.
100. Alexandria folio, South Dakota, by J. E. Todd and C. M. Hall.
104. Silver City folio, Idaho, by Waldemar Lindgren and N. F. Drake.
105. Patoka folio, Indiana-Illinois, by M. L. Fuller and F. G. Clapp.
107. Newcastle folio, Wyoming-South Dakota, by N. H. Darton.
108. Edgemont folio, South Dakota-Nebraska, by N. H. Darton and W. S. Tangier Smith.
113. Huron folio, South Dakota, by J. E. Todd.

THE DRAINAGE OF PONDS INTO DRILLED WELLS.

By Robert E. Horton.

GENERAL CONDITIONS.

The extensive ice action of the Glacial epoch left portions of Michigan, Indiana, Wisconsin, and Minnesota covered with glacial drift to a great depth. Sand, gravel, and clay alternate in patches, but the soil is, as a very general rule, loamy and permeable in the lake-besprinkled regions. The rainfall is usually from 30 to 40 inches per annum, of which from 8 to 16 inches reach the streams as run-off, largely through springs and seepage.

PONDS.

On large districts the surface topography is moderately rolling, and, while sloping in a general way toward the larger water courses, contains innumerable slight hollows without outlets. These undrained depressions vary in character from very small sink holes, generally tillable, in which standing water is found only after heavy rains or in early spring, to lakes, the vast majority of which are less than 1 square mile in area and which drain sloping margin lands from five to fifty times their own extent.

In the region in which these kettle holes and ponds are common no direct surface run-off to the streams takes place over a considerable percentage of the area nominally tributary to the rivers. Data regarding water-surface evaporation in this region is very meager, but it may be said, in a general way, that the annual evaporation from the lakes about equals the rainfall, the evaporation being greater or less than the precipitation according as the season is wet or dry. For these ponds to persist at a nearly uniform level requires that the inflow plus the rainfall on the surface shall equal the annual losses by evaporation and percolation.

DRAINAGE OF PONDS.

Ponds of this character disfigure valuable farms, and, if drained, the rich, mucky soil reclaimed would in many cases be of great value. Special attention was called to the desirability of their drainage by the excessive high water which followed the melting of the unusually large snow accumulation of the winter of 1903–4.

One of these ponds, which has an area of 4 or 5 acres when full and directly drains perhaps 60 acres of rather steep and permeable land surface, and which has been observed in a general way through many years, has shown a variation in its high-water level of 3 to 4 feet. It is filled with grass, promoting evaporation, and in a dry season goes entirely dry for a few weeks. The soil beneath is probably impervious or nearly so, and there are no marshes nor visible springs which feed it.

SUBSOIL DRAINS.

An unsuccessful effort was made twenty-five years ago to drain the above pond by digging through the hardpan bottom and inserting a stone-filled curb. This method of draining into a porous subsoil is considerably used in France and elsewhere,[a] but was entirely without success in this case.

DEEP-WELL DRAINS.

Surface drainage being unfeasible, drainage into deep-drilled wells has been successfully tried in a number of cases in Jackson County, Mich., and vicinity. An ordinary well-driller's outfit may be used.

In drilling the well on Fred Watkins's place, in Parma Township, after the first water bed had been reached at a depth of about 90 feet, the pipe was allowed to project upward in the pond near the surface, and was not protected in any way. The rate at which the water from the pond flowed down the drainpipe, rapid at first, decreased greatly during the first week and afterwards more gradually, so that after two months the pond, though visibly lowered as compared with adjacent undrained ponds, yet was not dry.

The well was then drilled out to a depth of 170 feet and the intake protected, with the result that the water was sucked down the pipe very rapidly and the pond completely drained. This well drains an area of about 35 acres of sloping tilled land, the soil being a permeable gravelly loam. The pond area was 2½ acres, and the pond seldom or never dried up. In the valley of Kalamazoo River, 4 miles distant, prolific artesian waters are obtained from a water horizon which has very nearly the elevation of the bottom of this

[a] Charpentier de Cassigny, J., Hydraulique Agricole.

drain well, and from which the water rises to an altitude about the same as the static head in the drain well.

Decrease of draining power of wells.—Several theories have been advanced for the rapid decrease in flow sometimes noticed, as in this case, after the opening of such wells. First, it has been suggested that an unsaturated pocket has been entered, but this appears doubtful from the rather permeable character of nearly all the material penetrated, and also from the fact that abundant water supply is always found in wells drilled to about the same depth in the surrounding region. Second, it appears possible that the percolating chamber below the bottom of the well casing may have filled by caving, reducing the percolating surface. This is not improbable, as a similar adjacent well, drilled for water supply in 1888 in the same siliceous material, caved frequently at first and still continues to do so at intervals, rendering the water very turbid. The effect of such caving in a drain well would probably be deleterious. The use of a perforated strainer point, as in driven wells, might be advantageous. A third possible cause of decreased flow is vegetable fibers and silt carried down the pipe owing to lack of screens. At the start the pond was full of vegetable matter resulting from the decomposition of pond lily and other aquatic plants, and long fibers could be seen entering the pipe. These would obviously collect on the percolating surface of the well and there form a matrix.

Efficiency of wells for draining.—The efficiency of such drain wells lies in their ability to draw down the accumulated waters resulting from melting of the snow, which usually takes place in March, sufficiently early to permit tillage at some time between about the first and the middle of May. The annual spring filling of the pond once removed, further filling will only result from excessive rains during the growing season, a contingency which can only be provided against by the use of a well of such capacity that the standing water will not ruin the growing crop before the well can draw it down. Such summer freshets will, however, occur at intervals only.

The pond being disposed of, tile drains may be needed to sufficiently dry the subsoil for tillage, and this requires that the inlet to the well shall be placed sufficiently below the bottom of the pond to receive their effluent.

Cost of drain wells.—The cost of a drain well increases with increased diameter; the price charged for a 3-inch uncased well is 70 cents and for a 4-inch one 90 cents a foot; casing costs in addition 25 cents and upward for each foot.

Capacity of drain wells.—The capacity of the drain pipe increases rapidly with increased diameter, first, because its area of section is proportionate to the square of its diameter, and, second, because the

loss of head and velocity due to friction are less in a large than in a small pipe with a given velocity. A drain well can take care of no more water than can flow out into the water-bearing material at the bottom, and the effect of an increase in size of drain well depends largely on conditions at the bottom of the pipe, as will be explained. Rapid drawing off of the water in spring is the most essential requisite, and this requires that the efficiency or capacity of the drain well shall be as great as possible.

There are some matters connected with the attainment of this end that are not well understood by the drillers of such wells where the writer has observed them and that offer an interesting problem in hydraulics.

Underground conditions.—(*a*) The drain well may penetrate an open fissure in which flows a free stream of water. This may occur, for example, in limestone formations. It is to be regarded, however, as accidental, and is not—as some are led to believe from the great water-taking capacity of some drain wells—either a common or a necessary condition in such wells. For such a well the capacity of the drain up to the limit of the capacity of the fissure would be almost directly proportional to the capacity of the drainpipe, the condition being that of flow through a pipe with free outlet. (*b*) The drain outlet may be in porous rock, as sandstone. The water-carrying capacity of sandstone is not always fully appreciated; the porosity, or percentage of voids, commonly ranges from 5 to 20 per cent, 15 per cent being perhaps a fair average. The water-taking capacity of the sandstone will differ from that of a loose sand of the same material only as a result of their different degrees of compactness. (*c*) The drain well may enter a porous stratum of sand, gravel, or other earth.

The wells described in southern Michigan apparently penetrate porous layers of glacial drift or sandstone. The outward flow is obviously the inverse of that which takes place when a well in the same water-bearing material is drawn upon by pumping. The laws that control such flow from wells where the head is known have been fully worked out elsewhere.[a]

Such calculations, together with the known yield of artesian and pumped wells in the same or similar formations, abundantly prove that the water-bearing material encountered in the drain wells of southern Michigan is capable of caring for the apparently large inflow observed.

In fig. 2 the conditions which may occur in such a well are illustrated. The water is disposed of by flowing outward through

[a] Turneaure and Russell, Public Water Supplies, pp. 267–275.

the pores in the material forming the walls of the chamber at the bottom, and the rate of such outward flow is determined by the pressure head, the surface area of the chamber at the bottom of the well, and the size of the pores.

Assuming that the water would rise in the well to the level A (static level) if there were no inflow, but that the inflow at the top

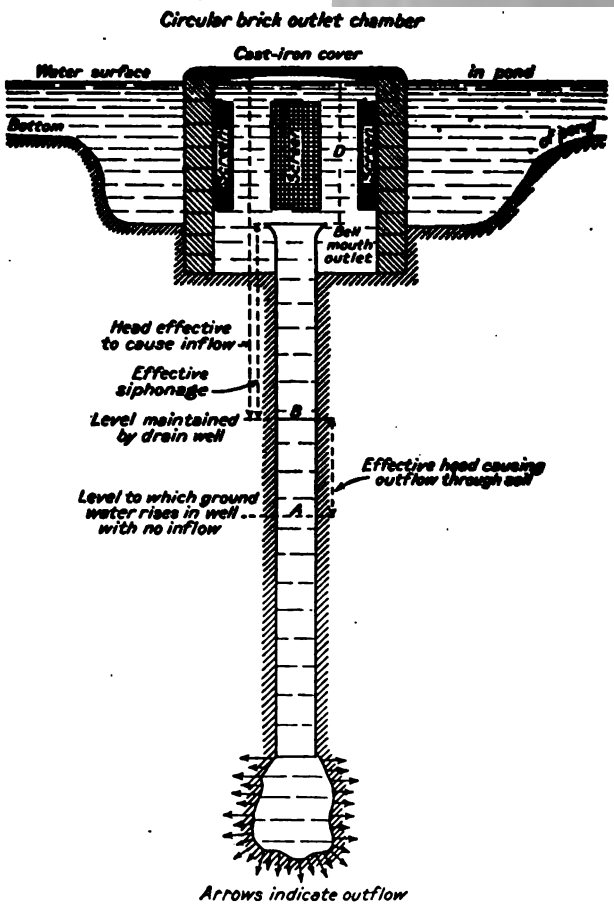

FIG. 2.—Diagram illustrating conditions in drainage wells.

of the pipe raises the water level to B, then AB is the effective head which causes discharge at the bottom. Later we shall consider siphon or draft-tube action in the pipe. Assuming for the present that water flows into the pipe as through an orifice, then the inflow to the mouth of the pipe will be proportional to the square root of the depth D of water above its mouth, indicating that in this case the intake should be placed low.

The mode of flow down a pipe, as commonly constructed by the drillers, is shown in fig. 3. This forms what is called a "Borda mouthpiece" and has a very low capacity. Only from 50 to 75 per cent of the pipe is effective, owing to contraction. If, however, a bell mouth be added to the pipe, having the form of the vena contracta, as shown in fig. 4, the full area of section will be effective, and the water will flow down the pipe with a velocity equal to about 96 per cent of that due to the head D.

Thus, a well fitted with a bell mouth may take 1.8 times as much water as one without. If the static level A is some distance below ground, the well will adjust itself to taking care of the increased supply of water provided by the bell mouth by increasing the head AB in about the same proportion that the inflow is increased, barring friction loss in the well pipe, a factor yet to be considered.

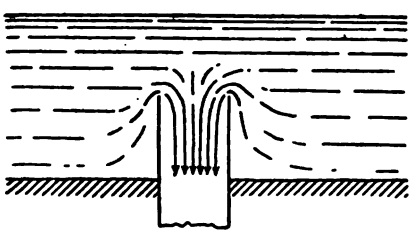

FIG. 3.—Diagram showing entrance of water into drainage pipe.

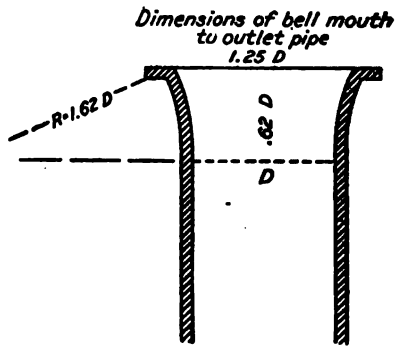

FIG. 4.—Diagram of mouth of drainage pipe.

In a well having tight casing and a proper entrance the inflow will be augmented by siphonage or draft-tube action, the water being forced down by atmospheric pressure in a manner the inverse of the action of a lift pump. If there be free discharge at the bottom and if the well be over 33 feet deep, then the maximum possible draft-tube head of 32.8 feet may be available.

Unless the ground-water horizon is at exceptionally great depth, however, it will probably happen, as has been observed in practice, that the discharge head h, required to take care of this large inflow of water, will cause the water level B to rise within much less than 32.8 feet of the surface, limiting the siphon head and dividing the total static head from A to the water surface of the pond in such a manner that the inflow head will just supply such a quantity of water as can be forced out of the bottom of the well by the remaining or discharge head. In any event the gain in capacity and rate of drainage which will result from siphonage will be very great; for

example, with a pressure head D of 1 foot over the inlet, the discharge would be nearly doubled by the addition of 3 feet of effective siphonage and nearly trebled by the addition of 8 feet of effective siphonage.

Expressing the above relations mathematically,

$$Q=CA\sqrt{2g\left[H+(h-h_f)-K\frac{V^2}{2g}\right]}$$

Where Q=Discharge in cubic feet per second.
A=Area of cross section of pipe in square feet.
H=Depth of water above top of pipe.
h =Effective suction head.
h_f=Friction loss in pipe.
V=Mean velocity in pipe.
K=A coefficient, such that $K\frac{V^2}{2g}$ equals the combined entry head and head required to produce velocity. In general, V is unknown, and this factor being small, may be neglected.

The friction head h_f for various sizes of pipe, together with the entry and velocity head for various velocities, may be found in books on hydraulics.[a]

Velocity of flow.—The velocity of flow in the drainpipe may be measured by means of a simple Pitot tube of glass inserted vertically in the top of the pipe, the short end projecting upward and having its mouth near the outer end of the drainpipe and a few inches below the top of the pipe. If h is the height in inches to which the water rises in the long leg above the pond surface, then the velocity of downward flow in the pipe will be very nearly

$$V=\sqrt{\frac{64.32h}{12}}=2.32\sqrt{h}$$

The flow in cubic feet per second will be

$$Q=0.0055\ d^2\ V=\frac{d^2\sqrt{h}}{80}\text{ nearly,}$$

d being the inside diameter of the pipe in inches.

The quantity Q should be somewhat reduced by the use of a correction coefficient depending on the form of inlet to the pipe. With good siphonage this coefficient will be near unity.

The theory of flow from wells rests upon the assumption that the ground-water horizon is sensibly affected only within a certain mean radius of influence. There is no method of accurately determining

[a] Weston, Friction of Water in Pipes; Coffin, Graphical Solution of Hydraulic Problems, etc.

this radius in the case of a drain well, but as large variations in its value affect the result but little it may be assumed, and if the other necessary factors are known the discharge may be calculated.

WATKINS'S DRAIN WELL.

Without entering into details, the following example may be given to illustrate what takes place in a 3-inch drain well 170 feet deep, in which the water rises statically to within 25 feet of the top of the pipe and to within 27 feet of the pond surface, assuming that the outflow is into a sandstone stratum 100 feet deep, having a porosity of 15 per cent, and an effective mean-grain diameter of 0.15 millimeter. These conditions are practically those in Watkins's drain well, Parma Township. (See fig. 3.) From Turneaure and Russell's Water Supplies and Weston's Tables[a] it is found that the drain would carry down 165,000 gallons per day, or one-fourth cubic foot per second, and that the total available head of 27 feet would be utilized about as follows:

Utilization of head in Watkins's drain well.

	Feet.
Overcoming friction in pipe	6.0
Velocity head	.45
Entry head	.2
Head causing outflow at bottom of pipe	20.0
Total	26.65

A well drawing 1 cubic foot per second will lower a pond of 1 acre area about 2 feet per day, providing there is no inflow. It will lower a 2-acre pond 12 inches per day, and so on. The well in the above example should lower a pond of 2.5 acres area about 2½ inches per day. If the pond were filled to an average depth of 2 feet at the end of March, the water should be drawn off and the subsoil sufficiently drained to permit tillage early in May. Early in 1905 the Watkins pond, which is fed by two lines of drain pipe, was well filled by the rains and melting snows, but was drained completely by the latter part of May. At the same time adjacent undrained wells remained nearly full.

SUMMARY.

Owing to low water at the time when visited, the writer had no opportunity to measure the actual rate at which any of the Jackson County drain wells take water. Such measurements would be of value in estimating the required size and probable efficiency of other wells.

[a] Loc. cit.

In conclusion, the importance of a capacious percolation chamber at the bottom of the well, and of suitable screens to protect the inlet, may be emphasized. A screen over the mouth of the pipe should not be used, as it will reduce the inflow head, but an ample catch basin of brick or large tile surrounding the well is very desirable. This should have ample openings covered by screens—preferably by double screens. A suggestion for a suitable intake is shown in fig. 4.

Experience has shown that in any locality success by this mode of drainage can not be assured beforehand. In some cases failure has probably been due to improper methods.

The effect of this manner of drainage is to forcibly inject the waters of the pond into the ground-water bed. If the drainage waters are impure the pollution may be detectable in surrounding wells which penetrate the same water horizon.

STATISTICS OF DRAIN WELLS IN SOUTHERN MICHIGAN.

The following details regarding drainage and other wells in southern Michigan have been compiled chiefly from data furnished by Mr. Charles Winchester, well driller, of Jackson, Mich., and by Mr. Carl Horton. A number of artesian wells are included which have been drilled for drainage purposes, or in places adjacent to drain wells.

(1) Miran Clark, Jackson County, Mich.; 3-inch drilled well, total depth 75 feet. At this depth an artesian stratum was entered raising water 6 inches above the surface.

(2) Henry Sussex, near Jackson City, Jackson County, Mich.; 3-inch well drilled to 100 feet depth. At this depth an artesian basin was entered which raises water 7 feet above the ground surface.

(3) Truman Eggleston, near Parma, Jackson County, Mich.; 3-inch well drilled to 47 feet depth. Drains a pond 2 to 3 acres in extent. The reclaimed land is used for wheat growing.

(4) George Eggleston, near Parma, Jackson County, Mich.; 3-inch well drilled to 42 feet depth. At this depth an artesian basin was entered which raises water 6 inches above the ground surface, rendering the well useless for drainage purposes; further drilling is contemplated.

(5) Edward Burt, Jackson County, Mich.; two 3-inch wells, the first to a total depth of 32 feet, of which 19 feet are in rock; the second to a total depth of 46 feet, of which 22 feet are in rock. The two wells are 15 rods apart; the second affords a successful drain.

(6) Arthur Morrell, near Jackson City, Jackson County, Mich.; 3-inch well drilled to 147 feet depth. It yields an artesian stream rising 6 feet above the ground surface.

(7) Bullen Brothers, Parma County, Mich.; 3-inch well drilled to 34 feet depth. It yields an artesian flow raising water 12 to 18 inches above the ground surface. This is distant but a few miles from several successful drain wells. It is apparently an artesian well in stratified glacial drift.

(8) Charles I. Moe, Jackson County, Mich.; 3-inch well, at first drilled 116 feet without success. Afterwards it was drilled 32 feet farther, making the total depth 138 feet, and giving a successful drain, which reclaims about 10 acres.

(9) Fred Watkins, Parma Township, Jackson County, Mich.; 3-inch well, with a total depth of 170 feet, 48 feet at surface through sand and clay and 122 feet through apparently soft stratified rock. Water rises in well within 25 feet of the surface. The pond had an area of 2½ acres and seldom or never dried up. Soil muck, with clay underneath. Two lines of draintile 5 feet in depth have been used to drain the soil. Tributary area to pond, about 35 acres of tilled land.

(10) Ebb Burch, near Concord, Jackson County, Mich.; stated to have three successful drain wells.

(11) Frank Roe, near Bath Mills, Jackson County, Mich.; stated to have had 3-inch drain well in use for eighteen years, reclaiming a marsh; depth, probably 75 feet.

(12) V. R. Horton, Parma Township, Jackson County, Mich.; 4-inch well drilled 70 feet through stratified drift, followed by 143 feet in shales and sandstone; total depth, 213 feet, of which 75 feet was cased with 4-inch pipe. Well located in pond of 4 to 6 acres area, which became dry in some seasons. Shallow muck bottom covered with grass; drains about 60 acres steeply sloping tilled land. This well began to take water when about 170 feet deep. It drained very rapidly for a time, but gradually decreased in capacity, apparently as a result of caving or clogging of the pores in the discharge chamber. A measurement of the rate of flow by Pitot tube was made March 28, 1905, by Mr. Carl Horton. The well was then taking about 6 cubic feet per minute.

(13) W. H. Hartwell, Albion, Calhoun County, Mich.; 4-inch drilled well 37 feet depth, probably in glacial drift. Successfully drained pond of 1 acre area in a deep glacial depression 1 mile from Kalamazoo River and at a considerably greater elevation. Land area tributary to pond, perhaps 40 acres.

(14) ———, Ingham County, Mich.; 2 or 3 inch pipe; total depth, 138 feet—90 feet through sand and gravel, 48 feet in sandstone. Well afforded successful drain of surrounding marsh land, but has been closed to avoid possible pollution of ground water.

TWO UNUSUAL TYPES OF ARTESIAN FLOW.

By MYRON L. FULLER.

INTRODUCTION.

As work on underground water progresses many variations and peculiarities in the conditions giving rise to flowing wells are brought to light. In another paper in the present report Dr. G. O. Smith has described certain flowing wells in crystalline rocks of Maine and New Hampshire and has explained the conditions governing their occurrence. It is the purpose to give in the present paper brief descriptions of two unusual types of flow.

In the first of the two types the flow takes place from essentially uniform sand, there being nothing which in any sense forms an impervious cover. In the second the flow is of rock water from the rock, although the confinement is not due to rock structure nor the head dependent upon the rock outcrop, but rather upon overlying deposits of drift.

FLOWS FROM UNCONFINED HORIZONTAL SANDY STRATA.

This peculiar type of artesian flow, which is sometimes encountered by engineers and others in their investigations of the water resources of regions of prevailingly sandy materials, apparently defies the commonly recognized requisites of artesian wells, presenting a problem of unusual interest and one which at first sight appears difficult of solution.

The essentials for artesian flows, as defined by Prof. T. C. Chamberlin in his treatise on artesian waters,[a] are a pervious bed lying between two impervious beds and having its outcrop at a height greater than that of the surface at the well adequate rainfall, suitable outcrop, and absence of leakage being assumed.

The requisites as defined by Professor Chamberlin, the most essential features of which are the impervious confining beds and the inclination of the strata, have been almost universally accepted by writers on the subject, but recent investigations, some of the results of which

[a] Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 134-135.

are here represented, have shown that true artesian flows may take place where both of these conditions, supposedly indispensable to flows, are absent. In fact sands which are pervious throughout and which are horizontal will often, when penetrated, yield flowing wells. The principal governing such flows was, to a certain extent, recognized by Chamberlin, who states in the report cited (p. 138) that the water itself may act as a confining agent, but in his descriptions and illustrations two confining beds are always recognized, the water through its pressure acting simply as an adjunct to the upper confining layer in preventing leakage or increasing the head. The possibility of flows from uniform materials does not seem to be recognized.

EXAMPLES ON LONG ISLAND, NEW YORK.

In an investigation of the water resources of Long Island, New York, conducted by the Survey in cooperation with the commission on additional water supply for Greater New York, a study was made of the ground water near the base of certain high bluffs bordering the deep, narrow depressions constituting the bays of the north shore.

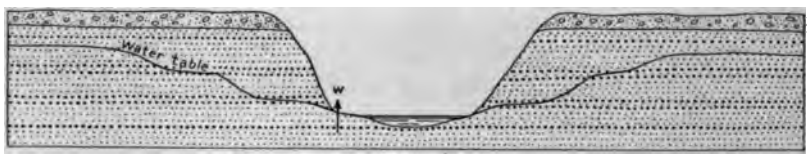

FIG. 5.—Diagrammatic east-west section across the bays on the north shore of Long Island, New York, showing horizontal stratification of beds, form of water table, and position of flowing wells.

The materials in which the bays are cut consist of gravels and sands, largely the latter, with no clays or other impervious materials. They are essentially horizontal and form an imperfect terrace about 200 feet above sea level, as shown in the accompanying profile (fig. 5).

The sands, even of the finer varieties, were invariably pervious, and the water table appeared to exhibit in the main the regular curve characteristic of uniform materials, although irregularities, due to varying coarseness, doubtless exist. Notwithstanding this, wells penetrating below the water table at points near the base of the bluffs (W, fig. 5) obtained flowing water. Mr. A. C. Veatch, who investigated the problem for the Survey, decided that the occurrence of flows depended upon slight differences in the degree of porosity of the sands, which, however, were in all cases pervious throughout. Beyond the determination that a slight difference in porosity was sufficient to determine an artesian horizon,[a] however, nothing definite was discovered as to the exact differences in texture necessary to give rise to flows. In a way the conditions are in harmony with a part of

[a] Science, n. s., vol. 19, 1904, pp. 795–796.

those outlined by Chamberlin, the finer materials, though entirely pervious, opposing the passage of water to a greater extent than the coarser material. Pressure, however, is readily communicated through the sand, even where there is much resistance to the movement of the water, and as the well pipe affords a less resistance to the upward passage of the latter as compared to that presented by the finer sands, flows take place.

EXAMPLES IN MICHIGAN.

Character of flows.—During the summer of 1904 an investigation of the waters of the Michigan drift was undertaken by the Geological Survey, during which 300 or more flowing-well areas deriving their supplies from the glacial drift were studied. One of the most interesting features brought out was the occurrence, as on Long Island, of flows from wells sunk wholly in sand. The topographic conditions are similar to those in the locality previously described, the wells being located on broad valley deposits, or terraces or plains of sand, above which rise higher moraines or other glacial deposits. The wells are almost invariably located at the base of the slopes of the latter, where they merge into the lower plains, etc. Commonly they meet with more or less clay, but numerous cases were reported where only sand was encountered. It is the flows from the latter which are of special interest.

In many instances it is probable that, as on Long Island, more or less marked differences in texture exist in the sands of the wells, giving rise to the flows, but in other cases it was established that flows could be obtained where the sand was of so uniform a texture as to present no recognizable difference in the size of the grains. It was further found that such occurrences were not isolated, but of widespread distribution, the flows apparently resulting from some cause other than difference in texture, and depending on a seldom recognized but widely prevalent type of artesian conditions.

Cause of flows.—The cause of these flows is probably to be found in the arrangement and shape of grains. All the materials from which the flows of the nature described are obtained are stratified; in other words, were deposited as layers, which, though composed of material of uniform grain, were nevertheless laid down successively one over another as horizontal laminæ. It is characteristic of this process to develop conditions more favorable to the transmission of water along the laminæ than across them, this being due in part simply to the lamellar arrangement.[a] There is, however, another factor present—

[a] This overlapping of grains has been described by W. O. Crosby in his discussions of "hard packed" sand in glacial deposits at Clinton, Mass. (Techn. Quart., vol. 17, 1904, pp. 61–62 and 67–70). Although such sand is so deposited or "packed" that it strongly resists the advance of the drill it nevertheless absorbs large quantities of water.

namely, the irregularity of the shape of grains—which has probably considerable influence in regulating the flow of water through the sand. In sediments, such as gravel and sand, the particles, no matter how uniform their size, are not symmetrical in shape. One axis is almost sure to be longer than the other (fig. 6), and when deposition takes place there is a strong tendency of the grains to arrange themselves with the longer axis horizontal and with the grains overlapping each other to a greater or less extent, like the shingles of a house, though, of course, far less perfectly (fig. 7). Under such conditions it is clear that, although the material is perfectly pervious and may hold large amounts of water, the passage of water across the stratification will be difficult, at least as compared with its passage along the lines of bedding. When a well enters such material it affords an easy upward path for the water, as compared with the passage through stratified material of the character described, and a flow will often result.

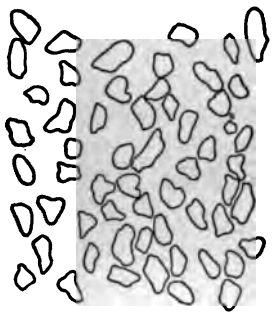

FIG. 6.—Shape of grains of a coarse sand; natural size. Drawn from photograph. (After King.)

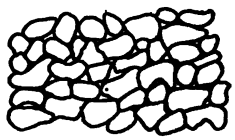

FIG. 7.—Overlapping sand grains, selected from those shown in fig. 6, and from other similar materials, when arranged with larger axes approximately parallel with one another; normal size.

Importance of principle.—The bearing of this particular type of flow on the water-supply problems of individuals or of small towns in the deeply gravel- or sand-covered regions of Michigan, Wisconsin, and other of the Northern States is important. It is no longer to be assumed that impervious confining beds are necessary to the flows which are so highly prized in many regions, but if the topographic conditions are such as to give the necessary head, flows may even be obtained in uniform sands. In the States mentioned it is rare that a well located at the base of any high elevation of sand or gravel or clayey materials fails to obtain flowing water (the exceptions being generally those wells penetrating nothing but clays), and pure ground-water supplies are awaiting development in hundreds of small villages in these regions. Most wells obtain flows at a depth of 100 feet or less, while wells over 200 feet deep are relatively rare. The flows are commonly confined to a strip along the base of the bluffs or slopes

about one-fourth or one-half mile in width, but occasionally artesian wells are found at considerably greater distances from the highlands.

PECULIAR ROCK FLOWS.

In one of the regions in southeastern Michigan visited by the writer in 1904 there were several flowing-well areas in which waters partaking of the character of rock waters rose under artesian pressure from the fissured surficial portion of the rock just beneath the surface clays.

The locality visited is in southern Wayne and northern Monroe counties and lies along the lower course of Huron River. The region is characteristically flat, the surface materials consisting in general of stiff, sometimes pebbly clays, covering to a thickness of from 20 to 60 feet a slightly irregular rock surface mainly of limestone or sandstone. The general conditions are shown in fig. 8.

From the figure it will be seen that the rocks, though dipping west at a rate of about 25 feet per mile, have been so eroded that their

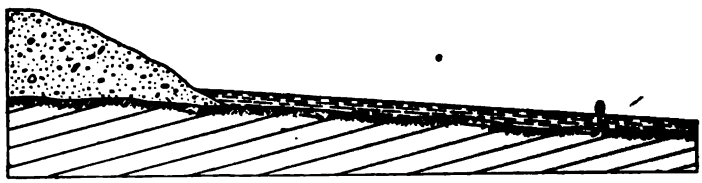

FIG. 8.—Type of artesian conditions in southeastern Michigan.

surface slopes not to the west, but to the east. The westward dip of the rock layers continues halfway across the State, after which the beds rise again, but they do not reach the surface anywhere in Michigan. Considering the general impervious character of the rocks, the remoteness of their western outcrop, and the fact that the elevation of the latter is nowhere sufficient to give the observed head at a point so far away, it is certain that the water can not come up the dip from remote sources. On the contrary, a careful study of the wells showed that the water simply occupied the fissured upper portion of the rock and moved eastward entirely independently of the character of the rocks or their dip. Following the wells westward, it was found that the source of the water was in the drift hills resting on the rock a few miles to the westward, against which the clays, serving as an impervious cap to the rock, terminate at a level higher than that of the flowing wells.

The fissures in the rock appear to be largely of the nature of joint and similar cracks, and were probably opened under the influence of the weather when the rock was exposed at the surface before its burial by the drift. Solution crevices dissolved in the limestone by

the percolating waters also form a part of the fissure system. In general the crevices are most numerous near the surface, the water being commonly found within a few feet of the top. It is probable, however, that some of the fissures reach considerable depths and will yield water to deep wells. The water in its passage through the rock dissolves from it more or less mineral matter, so that when it issues once more from the wells it possesses the characteristics of a rock water. In certain of the limestone areas it is high in sulphur, while at other points it is low in sulphur, but high in iron, etc.

Summarizing, it may be said that the district presents the anomalous condition of furnishing flowing rock waters, which, nevertheless, are not originally derived from the rock, but from the drift, are confined by drift, and depend upon the drift rather than the rock for their head. In fact, in all essentials they are drift waters, the rock simply serving as a carrier in place of the layer of stratified sand or gravel commonly present.

The conditions described are duplicated at a considerable number of points in southeastern Michigan, and the same explanation of the flows may apply to other artesian districts in the clayey flat lands bordering the lakes in Michigan and adjacent States. The part played by the surface clay as a retaining layer of rock waters suggests a possible explanation of the confinement in crystalline or jointed rocks that results in artesian flows.

CONSTRUCTION OF SO-CALLED FOUNTAIN AND GEYSER SPRINGS.

By Myron L. Fuller.

IMPROVEMENT OF SPRINGS.

Where springs issue in transparent pools or as streams of clear water from the rock little can be added to their attractiveness by artificial means. In many places, however, the water of the springs seeps out slowly through the soil, the place of emergence being marked simply by a wet, grassy, or boggy spot. In such cases the springs may often be transformed by the construction of artistic basins, rocky arbors, rustic spring houses, and other similar means. One of the most useful methods of treatment is the construction of a so-called "fountain spring," while the most interesting in many ways, and the most puzzling to many, is the "geyser spring." Both are of simple construction and inexpensive, and the results under favorable conditions are quite striking.

CLASSES OF SPRINGS.

In the present discussion springs are, for convenience, grouped into two classes: (1) Hillside springs and (2) springs on flat or level lands. In either the water may or may not be under pressure or head. In those cases where there is no head the water can not be made to rise naturally above its point of emergence, but when under pressure it will, if confined, rise to a greater or less height above the point at which it issues.

Fig. 9 represents a hillside spring unconfined and without head, while fig. 10 shows a similar spring fed from waters confined between two impervious layers and under more or less pressure; only in the latter case will the water rise if confined. From either, however, a fountain or a geyser spring can be constructed if sufficient fall can be had close at hand.

Springs occurring on level land can also be classified according to the amount of head which their waters possess, which will vary in amount from just sufficient to bring the water to the surface to enough to make it boil strongly from the ground.

To test the amount of head of the water of a spring it is necessary to confine the flow. When this is low it can often be determined by inserting a bottomless barrel about the spring. If the water rises to a height considerably above the surface of the ground, and especially if the half-sunk barrel fills and overflows, it may be presumed that the water would under more favorable conditions rise still higher, and possibly the spring could be made into a "fountain spring."

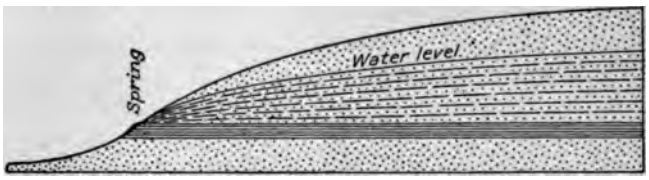

FIG. 9.—Hillside spring from unconfined water bed without head.

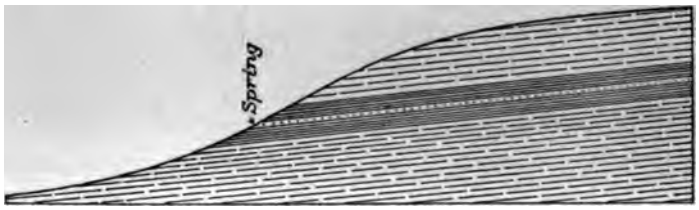

FIG. 10.—Hillside spring from confined water bed under more or less head.

CONSTRUCTION OF FOUNTAIN SPRINGS.

Definition.—The term "fountain spring" is here used to designate a spring the water of which is made to rise through a pipe to a point above the surface of the ground at the spring. It may flow gently from a pipe into a trough by the roadside or in the barnyard, into the sink in the kitchen, or it may, if the head is considerable, be made to throw a jet into the air as in an ornamental fountain.

Construction.—The aim in the construction of "fountain springs" is to confine the water and force it to rise, instead of flowing out uselessly upon the ground as in the undeveloped spring. To do this a circular excavation about 3 feet in diameter should be made about the spring, the earth being removed to a depth of 3 to 5 feet, or until a layer of clay or clayey sand is encountered. The excavation when completed should have the outline indicated by $e\ e^1\ e^2\ e^3$ in fig. 11.

A bottomless barrel ($b\ b^1\ b^2\ b^3$) may then be inserted and an upright pipe placed in the center with its bottom nearly level with the lower edge of the barrel. Around the pipe inside the barrel are packed rounded stones (G) 3 or 4 inches in diameter at the bottom, but gradually decreasing in size until a height of 2 feet is reached. About 6 inches of sand (S) should then be inserted, covered with an equal thickness of clay, or of as clayey sand or loam as can be found (C). This should somewhat more than fill the remainder of the barrel, and should be worked in around the edges on the outside until all avenue of escape of the water, except through the projecting pipe is cut off. The ground should then be leveled over and thoroughly tamped down. An auger hole bored through the clay at the point where the water rises (Sp) will sometimes improve the flow. In more elaborate constructions cement can be used to advantage in place of clay.

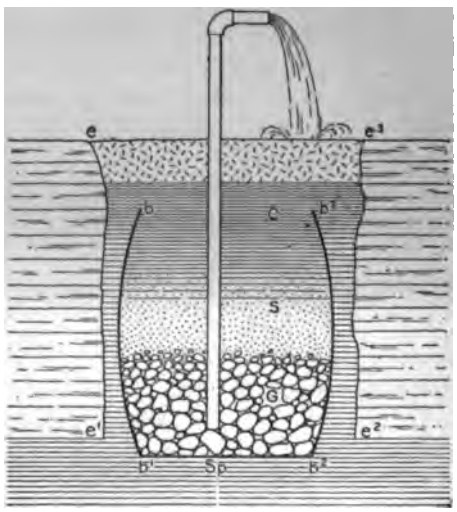

FIG. 11.—Diagram showing method of constructing a "fountain spring." Sp, point of emergence of spring; G, gravel; S, sand; C, clay; $b\ b^1\ b^2\ b^3$, sunken barrel; $e\ e^1\ e^2\ e^3$, outline of original excavation.

The result of this treatment is that the water of the spring, deprived of its ordinary outlet, is forced to rise through the pipe. The height to which it will rise and the force with which it will flow depends upon its head, which is in turn dependent upon the elevation of its source. There are many instances where the water is raised into roadside troughs, and its possibilities in connection with farm and household supplies are considerable. A few owners of important springs, as at the Nochemo Springs, Reed City, Mich., have by this or similar processes succeeded in obtaining streams which throw jets several feet into the air, making fountains of considerable beauty.

Unfortunately, not all springs can be converted into "fountain springs," but testing by means of the treatment outlined above is inexpensive and requires but a few hours of labor to complete. Something of the height to which the water will rise may sometimes be judged from the force with which it boils up in the bottom of the pools so frequently associated with the springs.

CONSTRUCTION OF GEYSER SPRINGS.

Definition.—By a geyser spring is meant one so piped that it will throw, at fixed intervals, a jet of water to a greater or less height into the air, after which the flow subsides and ceases until the lapse of another interval of time, when it again flows.

Necessary conditions.—To successfully construct a geyser spring it is necessary to find a spring at some elevation above the point at which the flow is desired and but a short distance away. A spring on a steep hillside, not more than 100 feet away from the desired point

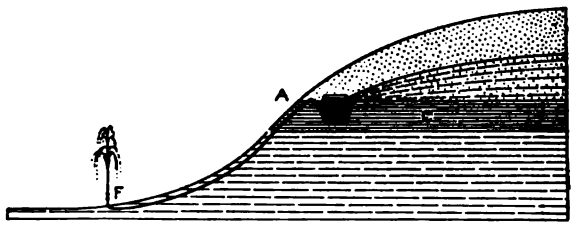

FIG. 12.—Diagram showing method of construction of "geyser spring." *A*, Normal point of emergence of springs; *C*, impervious stratum; *F*, geyser spring.

of flow and 15 to 20 feet higher, presents the most favorable condition. It does not matter in this instance whether or not the water is under pressure.

Construction.—The spring will nearly always emerge just above an impervious layer as at A in fig. 12. A little back from this point a small pit several feet deep should be dug and a barrel inserted with its upper edge about 6 inches above the top of the impervious layer. Holes should be bored in the sides to admit the water just above the clay, this part of the barrel being surrounded by fine gravel to keep the holes from clogging and to prevent clay and sand from entering. The barrel may be covered and the earth tamped down if desired. A pipe should finally be connected with the bottom of the barrel by a tight joint, and should lead upward sharply until about 6 inches below the top of the clay or a foot below the top of the barrel, when it should be bent gradually and carried downward below the surface at a depth just sufficient to prevent freezing, to the fountain, when

it should be bent again into a vertical position and brought surface. The pipe is in fact a simple siphon.

Operation.—The water gradually accumulates in the barrel it reaches a height equal to that of the upper bend of the si at which moment a flow is inaugurated, issuing at the fou at F. The flow will continue until the water is exhausted the barrel, when it will stop, only to commence again whe level of the top of the siphon is again reached. One preca however, is to be observed in regard to the working of the si namely, the capacity of the pipe should be greater than the ca of the spring, otherwise the flow once inaugurated will be contin

The height to which the water will be thrown depends prin upon the altitude of the spring above the fountain—the high spring the higher the jet. A decrease in the size of the jet wil within certain limits increase the height to which it will rise.

A CONVENIENT GAGE FOR DETERMINING LOW ARTESIAN HEADS.

By Myron L. Fuller.

One of the most important items in the investigation of artesian wells is the head, or height, to which the water will rise. Although the volume and velocity of discharge afford general indications of the head, other factors, especially the size of the pores of the rock through which the water passes, have an important modifying action upon the flow. The head which in a porous material will give a large discharge under considerable velocity may give only a small drizzle in a very fine-grained material, owing to the resistance of the latter to the passage of water. In most cases the exact character of the water-bearing horizon is not known, and even where known the flow may be dependent, not on the nature of the material in the immediate vicinity of the well, but on the average character of the material which the water has penetrated in its passage from its source to the point of emergence. This is known even more rarely than the character of the water bed at the well.

It being, therefore, commonly impossible to calculate the head from the volume or velocity of flow, it becomes necessary to apply some form of pressure gage to the well. This has often been done in the case of wells of high head in the more important artesian districts, but, because of the cumbersome character of ordinary gages and the difficulty of connecting them with the wells, they have been rarely used on small wells of low head, such as those which occur at many points in the drift-covered areas throughout Michigan, Wisconsin, and Minnesota.

The ordinary steam gage is about 5 inches in diameter and several inches thick, and its use has commonly necessitated considerable plumbing work in piping it on to the well. For some time the writer has sought for a gage of small size, capable of being quickly applied, and has at last found one of low price which will measure heads up

to 50 pounds, or about 100 feet, can be carried in the vest pocket, and can be applied to ordinary pipes and read in a second's time. It is described in the following paragraphs.

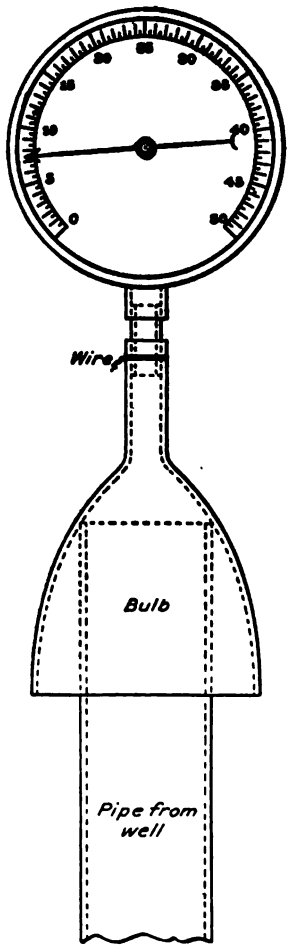

FIG. 13.—Convenient form of pressure gage and its application.

The gage adopted for the measurement of low pressures is 2 inches in diameter and 1 inch in thickness. The type commonly used is nickel plated, though it can be obtained plain, and the face is protected by a thick beveled crystal. The dial is graduated in pounds and reads up to 50, each fifth pound being marked by figures (fig. 13).

Into the stem of the gage a small three-eighths inch metal tube, about an inch in length, is screwed, over which is stretched and wired a rubber tube which opens out into a broad flange 2 inches or more in diameter (fig. 13). This peculiar tube, though appearing at first sight of a character difficult to obtain, may nevertheless be secured at any drug store, and is made by simply cutting through the middle of the bulb of a large-sized syringe.

In the case of small wells, such as those for which the apparatus was devised, the diameter of the pipe from which the flow issues is commonly from one-half to 1 inch, and will rarely exceed 2 inches. In applying the apparatus take the gage in the right hand and at the same time slip the open half of the rubber bulb over the end of the pipe, holding it firmly so that no leakage takes place. With discharge pipes up to 1 inch in diameter and with heads within the limits of the gage this can be done without difficulty, and the pressure read immediately from the dial. With 2-inch pipes the gage can not be used satisfactorily for pressures much greater than 25 pounds per square inch.

WATER RESOURCES OF THE CATATONK AREA, NEW YORK.

By E. M. Kindle.

LOCATION.

The area here considered lies to the southeast of the Finger Lakes region of New York and has for its southern boundary the New York-Pennsylvania State line. It is about midway between the east and west boundaries of the State. Four 15-minute quadrangles, known as the "Dryden," "Harford," "Owego," and "Apalachin," comprise the area. The city of Ithaca lies near the northwest corner of this area, but only partly within it. Binghamton lies near the southeast corner, but just outside the area.

TOPOGRAPHY AND GEOLOGY.

The region is one of strong topographic relief, the hills reaching a maximum elevation of 2,000 feet, with an average elevation of, perhaps, 1,500 feet. The drainage is principally to the Susquehanna River, which crosses the southern part of the area from east to west. The drainage of the northwestern part of the area, including most of the northern half of the Dryden quadrangle, discharges into Lake Cayuga. All of the principal valleys lie between the 800- and 1,200-foot contours except Cayuga Valley, which just enters the region on the northwest and has an elevation of between 380 and 400 feet at Ithaca. Shales and sandstones of upper Devonian age comprise the surface rocks of these quadrangles. The rocks lie approximately horizontal, with a general but small southerly inclination, interrupted over a part of the area by very low folds with east-west trend. Glacial deposits of clay, sand, and gravel cover the whole of the region.

WATER RESOURCES.

WELLS.

The sandstones and shales which constitute the consolidated rocks of the region are comparatively impervious to water, and relatively few wells or springs derive their supply from them. The glacial

till, with its interbedded sands and gravels, acts throughout the whole region as a reservoir, from which wells from 10 to 40 feet deep usually obtain a satisfactory supply of water for domestic pusposes. Springs are common on the hill slopes and supply flowing water to a large number of farms.

The wider and deeper valleys of the region have very generally been deeply filled by drift. The complicated structure of this filling, which frequently includes alternating beds of clay, gravel, and sand, affords in some localities artesian-water conditions. It probably includes in all cases sand or gravel beds between more or less impervious beds of clay. These coarse beds are doubtless connected by more or less continuous deposits of water-bearing materials reaching diagonally across or rising between the impervious beds and connecting with the alluvial fans in front of the mouths of streams descending to the valleys from the hills. A continuous waterway is thus formed from the gravel fans, which absorbs all of the water at the mouths of many small streams, except in times of flood, to the buried sheets of sand and gravel.

Ithaca wells.—The most important of these artesian-water areas is that of the Ithaca delta at Ithaca, which is partly in the Dryden and partly in the Ithaca quadrangle. Well records show the maximum thickness of the drift filling here to be 400 feet. A large number of wells at Ithaca have secured artesian water at depths of from 70 to 100 feet. The wells which afford large flows, however, all go deeper than this.

More than a dozen wells, a majority of which have been successful, have been sunk just south of the city of Ithaca for the purpose of securing artesian water for the city, which it is purposed to supply entirely from this source. The first of the series was estimated to yield a daily flow of about 300,000 gallons. The records of these wells[a] show, first, a bed of fine-grained massive clay 40 to 60 feet thick. Coarse water-bearing beds of sand and gravel follow the clay to a depth of 60 to 120 feet. These are underlain by a second clay series extending to a depth of from 200 to 280 feet. Below these in every well are found coarse-textured beds, including some sand and gravel. These are the principal water-bearing beds and vary in texture from coarse gravels to fine "quicksand," which last is sometimes forced by the water under pressure into the pipes in sufficient quantity to stop the flow. The largest flow is obtained from the coarse gravels.

According to Professor Tarr, the origin of the artesian water at Ithaca is, in the case of the upper water-bearing horizon, "the alluvial fans opposite the mouths of the streams that descend to the Ithaca delta."[b] The water found in the deeper sands and gravel is

[a] Jour. Geol., vol. 12, 1904, pp. 69-82. [b] Id., p. 81.

believed to originate in "the moraine which occupies the Cayuga Valley from the divide nearly to the well sites, a distance of over 11 miles."*

Slaterville Springs wells.—A number of flowing wells are located in the broad valley of Sixmile Creek, in the vicinity of Slaterville Springs. These usually reach the artesian-water horizon in a bed of sand or gravel at from 44 to 74 feet below the surface. The flow is small, usually not exceeding 5 gallons per minute. Much of the water is mildly chalybeate in character and carries small quantities of calcium carbonate, magnesium, sodium, and potassium. It is considered to have medicinal value, and the village has become a popular summer resort on account of it. A successful attempt was made at the creamery to secure water free from the mineral properties characterizing many of the wells. Two wells, respectively 110 feet and 76 feet deep, secured flowing water in sand free from mineral constituents.

Other artesian wells.—Other localities at which flowing wells occur in this region are as follows: One mile west of Brookton on the land of D. C. Hanford, at Newark Valley on the property of Jabez Smith, and just north of Tioga Center.

MINERAL SPRINGS.

Several springs whose waters contain sulphur or other minerals occur within this region. The following list includes those which have been visited by the writer, but is probably incomplete:

Dryden.—West of Dryden one-half mile a chalybeate and a sulphur spring are located within a few feet of each other. A summer hotel has been located near the springs for many years. The sulphur spring has a strong sulphurous taste and is favorably known for its medicinal properties.

Speedsville.—A sulphur spring is located about 1 mile northeast of Speedsville on the east side of Owego Creek Valley. The water is used for stock.

Nanticoke.—Nanticoke spring is located 1 mile south of the village of Nanticoke in a small valley running northwest from Nanticoke Creek. The spring apparently rises through the drift, but the proximity of bed rock is shown by an outcrop of sandstone and shale a few yards away. The water tastes rather strongly of sulphur and coats the sides of the spring with a white deposit of that substance. The water is used for domestic purposes.

Spencer.—Two springs known as Spencer Springs are located in a small valley 3 miles northeast of Spencer. They occur in a seepage

* Jour. Geol., vol. 12, 1904, p. 82.

area of 60 or 70 square yards in the bottom of the valley. Three separate springs have been developed and inclosed in this seepage zone, two of which furnish strong sulphur water, which coats the channel leading from them with white sulphur; the third has a very mild mineral taste, with little or no sulphur. The place was formerly the site of a summer hotel, which was burned a few years ago.

Halsey Valley.—A sulphur spring is located 3 miles southeast of Halsey Valley on the west fork of Pipe Creek, issuing from the slope of a steep hill about 100 feet above the valley. There is a considerable flow of water, which is used for stock. This is the only mineral spring in the region that is located considerably above the bottom of the valley in which it is found.

Glen Cairn.—South of Glen Cairn 1¼ miles and about 4½ miles northeast of Waverly a sulphur spring occurs in a small branch of Ellis Creek Valley. The spring is located very near an outcrop of bed rock, from which it is probably derived. The flow is larger than that of most of the mineral springs, and contains considerable sulphur, which coats the sides of the spring. It is used for stock and domestic purposes.

Owego Creek.—Three miles south of the mouth of Owego Creek and near the head of Smith Creek there is a sulphur spring, which has a mildly sulphurous taste. The small flow is used for stock.

Source of the springs.—None of the mineral springs afford a large volume of water, the flow probably in no case exceeding 5 gallons per minute. All reach the surface through glacial deposits, but it appears probable that the sulphur springs derive their waters from the consolidated rock below the drift, possibly the Genesee. This opinion is based upon the following considerations: (1) Sulphur waters are derived from the decomposition of mineral sulphides, very frequently from pyrites; (2) there is a comparatively small amount of such minerals in the drift and a relative abundance of them in the Genesee and other upper Devonian rocks; (3) the Genesee and Portage are cut by well-developed systems of joints, which permit surface waters to penetrate and traverse them; (4) the general southerly inclination of the bed rock would cause waters traversing them to rise to the surface when the joint conditions were favorable; (5) just north of this region strong sulphur springs escape from the joints in the Genesee at points where the formation is exposed in post-Glacial gorges.

STREAMS.

The streams of this region derive their waters throughout the greater part of the year principally from seepage and from the springs in the assorted glacial material and till. A fairly uniform

supply is maintained, therefore, during the months of least rainfall, of water of excellent quality and purity when protected from barnyard contamination.

The streams furnish the principal source of water supply for the villages and cities within the area. The water supply for the Cornell University campus is derived from Fall Creek. The city of Ithaca derives the greater part of its water supply from Sixmile Creek.

A number of streams with moderate gradient have been utilized to furnish water power for sawmills and gristmills. Water power is thus used at Brookton, Marathon, Newark Valley, Owego, Candor, and other points. Streams possessing both a very high gradient and a considerable volume of water are confined to the northwest corner of the region and are two in number—Cascadilla and Fall creeks. Both streams have a fall of about 400 feet in 1 mile at Ithaca, but the latter is the larger and more important stream. It supplies power for three or four mills and factories and for the Sibley shops and hydraulic laboratory of Cornell University.

WATER RESOURCES OF THE PAWPAW AND HANCOCK QUADRANGLES, WEST VIRGINIA, MARYLAND, AND PENNSYLVANIA.

By George W. Stose and George C. Martin.

GENERAL CONDITIONS.

Potomac River divides the Pawpaw and Hancock quadrangles into two almost equal parts, the portion north of the river lying in Maryland and Pennsylvania and that south of it in West Virginia. The river here is about a quarter of a mile wide, and in most places is too deep to be forded. The only wagon bridge within the area is at Hancock, Md., and the only existing railroad bridges at Cherry Run, but the Western Maryland Railroad is now constructing four bridges for its new extension to Cumberland in the vicinity of Pawpaw. The only ferry within the area is at Cherry Run. At Great Cacapon, W. Va., the river is dammed to a height of about 15 feet to furnish water for a feeder to the Chesapeake and Ohio Canal on the Maryland side. A gristmill at Great Cacapon formerly obtained power from the same source. Pollution of the river is not excessive in this area, as there are few large towns or factories along the banks.

TOPOGRAPHY.

The area is essentially a hilly region, crossed by prominent ridges and mountains having a northeast trend, which are part of the Appalachian Valley system. The maximum elevation attained is 2,260 feet, in Cacapon Mountain. Sideling Hill, Town Hill, Sleepy Creek Mountain, and Third Hill Mountain are other prominent ridges, from 1,700 to 2,000 feet in altitude. The intervening areas are of a plateau character, deeply dissected by numerous streams. The valleys are narrow and steep and in general have a northeast-southwest course. The remnants of the plateau, the surface of which ranges in elevation from 700 to 1,000 feet, form narrow, flat-topped ridges, parallel to the longitudinal streams.

GEOLOGY.

The rocks are all sedimentary, and range in age from Ordovician to Carboniferous. They are closely folded in a northwest-southeast direction, and the truncated, steeply inclined beds, trending northeast and southwest, cross the entire quadrangle and control the development of mountains and valleys in this direction. Cacapon Mountain is composed of Silurian (Medina) quartzite, brought up by a bold anticline, while Sideling Hill, Town Hill, Sleepy Creek Mountain, and Third Hill Mountain are composed of Carboniferous sandstones infolded in synclines. The minor ridges are mostly monoclinal, composed of thinner siliceous formations in the Silurian and Devonian shales and limestones, on the upturned edges of which the plateau has been carved.

WATER RESOURCES.

STREAMS.

The chief tributary streams are Great Cacapon River, Little Cacapon River, Sleepy Creek, and Back Creek, on the West Virginia side of the Potomac, and Licking, Tonoloway, Sideling Hill, and Fifteenmile creeks on the Maryland-Pennsylvania side. These streams have a large flow of water, and the fords are deep, even at low stage. The water is clear and in general unpolluted. Many of the smaller streams also have a considerable flow of clear water suitable for water supply or for power. The water power of these streams is undeveloped, with the exception of that utilized by a few gristmills. An electric power and light plant of considerable magnitude, however, is at present under construction near the mouth of Great Cacapon River. Although deeply incised in the topography, this river has, in places, a very sinuous course, and 1½ miles southeast of the town of Great Cacapon makes an unusually long detour of 1¾ miles, whereas the direct distance across the neck is less than one-fourth mile. A rock tunnel 14 feet wide, 10 feet high, and 234 feet long has been cut through this neck, and a dam 15 feet high and 12 feet base has been built at the entrance. A fall of 18 feet is thus obtained, and it is estimated by the company that there is sufficient water, even at low stage, to furnish 750 horsepower. A direct-acting turbine of 600-kilowatt capacity is being installed. Wires have been strung to the towns of Great Cacapon and Berkeley Springs, which are to be lighted by electricity, and in time power and light will be furnished to all surrounding villages as far as Hancock. The plant is to be in operation early in 1905. The power thus made available at small cost will no doubt attract new industries to this sparsely settled portion of West Virginia.

SPRINGS.

MISCELLANEOUS SPRINGS.

Small springs are frequent where sandy strata or limestone are exposed, but large springs are not common in this area. One spring worthy of note is at Ziler Ford, W. Va., near the southern end of the Pawpaw quadrangle. A stream of such size issues from beneath a ledge of upturned limestone that it was formerly used to run a gristmill. It is now abandoned, however, and the mill has fallen into decay. Another important spring is at Indian Springs, Md., in the eastern part of the Hancock quadrangle, where a small but attractive hotel entertains many summer guests.

BERKELEY SPRINGS.

The most noted springs in the region are at Berkeley Springs, W. Va., formerly called Bath, in the western part of the Hancock quadrangle. They issue from the foot of a monoclinal ridge of steeply inclined sandstone (Oriskany), at the contact with overlying impervious shale (Marcellus).

History.—These springs have been resorted to for their health-giving properties for many years, and the names of Washington, Fairfax, and others dating back into the eighteenth century are closely associated with them. The road leading from Washington to the springs is known throughout this part of the country as the Warm Spring or Sir John Road. The following is an extract from Burke's Virginia Mineral Springs, 1853:

> These springs were the first known, as, assuredly, they are among the most important of the mineral waters of Virginia. They were frequented before the Revolution and visited by Washington and other distinguished personages, who had cottages erected for their own accommodation. The property of these springs was originally vested in Thomas Lord Fairfax, who made a grant of a few acres of land and the water privileges to the State, reserving to his own use one spring, still known as "Lord Fairfax's Spring," and thereon obtained a charter for laying off 50 acres as the site of a town, which was accordingly laid off and partially built upon. The State grounds and water privileges were vested in a body of trustees, whose successors continue to govern and control them.

The setting aside of this park as a State reservation is described by J. J. Moorman [a] as follows:

> The importance of this property was appreciated by the country at a very early period, for in October, 1776, in the first year of the Commonwealth, we find the following in the statute book of Virginia:
>
> "Whereas it hath been represented to the general assembly that the laying off

[a] The Virginia Springs, 1859.

of 50 acres of land in lots and streets for a town at the Warm Springs, in the county of Berkeley, will be of great utility, by encouraging the purchasers hereof to build convenient houses for accommodating numbers of infirm persons who frequent those springs yearly for the recovery of their health:

"Be it therefore enacted by the general assembly of the Commonwealth of Virginia that 50 acres of land adjoining the said springs, being part of a larger tract of land, the property of the Right Hon. Thomas Lord Fairfax, or other person or persons holding the same by a grant or conveyance from him, be, and the same is hereby, invested in Bryan Fairfax, Thomas Bryan Mastin, Warner Washington, Rev. Charles M. Thurston, Robert Rutherford, Thomas Rutherford, Alexander White, Philip Pendleton, Samuel Washington, William Ellzey, Van Swearengen, Thomas Hite, James Edmunson, James Nourse, gentlemen trustees, to be by them, or any seven of them, laid out in lots of one-quarter of an acre each, with convenient streets, which shall be, and the same are hereby, established a town by the name of Bath," etc. (Hening's Statutes at Large.)

The town was consequently laid off into lots in August, 1777. Among the purchasers were Charles Carroll of Carrollton, Horatio Gates, Gen. George Washington, and many others of note and distinction.

Berkeley Springs is now a fashionable watering place, and many of the best families in the East have handsome summer residences here. A beautiful park of several acres surrounds the springs, in which are located the bath houses and offices of the company controlling the property. Formerly a spacious hotel faced this plaza, but it was burned down, and another has had a similar fate, so there remains but one hotel, too small to accommodate the health and rest seekers during the summer season. Another large hotel adjoining the park is much needed to restore this resort to the place it formerly held as one of the leading watering places in the East.

Character of Berkeley Springs.—The Warm Spring ridge is composed of white porous sandstone, which crops conspicuously on its eastern face, dipping down the slope at about 50°. The black shale overlying the sandstone is exposed on the flanks of the ridge at many places. At the springs, however, the steep sandstone slope descends to the valley bottom so that the shale does not appear. The principal springs are four in number, but in reality the water seeps out continuously over a space of 100 yards. These four springs have been inclosed by stone walls, within which the sparkling water bubbles up through the white sand and gravel at the bottom. From these inclosures the water is piped into the bath houses. There are two large swimming pools, through which the water flows constantly at its natural temperature, and although these pools are 4½ feet deep, the remarkable purity of the water makes them appear very shallow. A newcomer always hesitates to dive into the pool for fear of striking the cement bottom. There are also a large number of tubs and small pool baths 3 feet by 6 feet in cross section and 4 to 5 feet deep, where the water is heated to any desired temperature by the injection of steam.

An analysis of the water, made for the company by J. H. Dickson, chemist, Pittsburg, Pa., and published in an advertising leaflet, is as follows:

Analysis of water at Berkeley Springs, W. Va.

	Grains per gallon.
Iron	0.506
Carbonate of lime	9.577
Carbonate of magnesia	1.951
Sulphate of lime	1.098
Chloride of sodium	.244
Silicic acid	.122
Total residue	13.498

Since the United States gallon contains 58,372 grains, the percentage of mineral matter in the water is small. The gas occurring in the spring water has been determined by W. B. Rogers[a] to be chiefly nitrogen, with a small amount of oxygen and carbonic acid. The water is regarded as beneficial, both as a beverage and for bathing, being especially recommended for rheumatism and gout. Its temperature of 73° F. makes it very comfortable for summer bathing, although in the swimming pools it loses some of its heat by radiation. On account of its temperature it is somewhat insipid as a beverage when taken direct from the spring, and some prefer to let it cool or use ice; but one soon becomes accustomed to drinking it and relishes it for its purity and sparkle. The mineral contents are not sufficient to give it a taste, and unless taken in large quantities it can hardly be classed as a mineral water. Some patients drink as many as thirty glasses a day.

Flow of Berkeley Springs.—It is difficult to determine the amount of flow from the springs, since the water is diverted to many channels, some being supplied direct to an electric-light plant and some piped into the town. A rough estimate was obtained by measuring the stream which flows away from the springs and calculating what is otherwise consumed. The flow for the combined springs as thus determined is 1,560 gallons per minute. In William Burke's report, referred to above, the flow is stated to be between 1,000 and 1,500 gallons per minute. This copious supply of crystal pure water is largely unconsumed and, except in the process of washing glass sand in the factories below the town, is unused, whereas millions of gallons could be bottled for domestic purposes and shipped to eastern cities at small cost.

Origin of Berkeley Springs.—The springs undoubtedly come from the sandstone forming the Warm Spring ridge. This is an unusually pure sandstone, quarried for glass sand at many points; yet it prob-

[a] Geology of the Virginias, p. 582.

ably furnishes the small quantity of minerals, chiefly carbonates of lime and magnesia, contained in the water. Since there is no indication of the volcanic or chemical origin of the heat, it is assumed that the waters have risen from a considerable depth, where the internal heat of the earth is sufficient to produce the temperature. At the rate of increase of 1° for each 50 or 60 feet of depth within the earth, which is the generally accepted average determined from deep mines and bore holes, the depth necessary to heat the water from 52°, the average temperature of the region, to 73° would be between 1,000 and 1,300 feet. It is considered, therefore, that the waters circulating through the sandstone at approximately this depth, unable to rise through the overlying impervious shale, find at this place some condition in the sandstone just beneath the shale favorable to their escape.

WATER RESOURCES OF THE NICHOLAS QUADRANGLE, WEST VIRGINIA.

By George H. Ashley.

LOCATION AND GENERAL FEATURES.

The Nicholas quadrangle is a 30-minute quadrangle with an area of nearly 1,000 square miles, located near the center of West Virginia, a little to the east of New and Kanawha rivers. It is within the area of the Allegheny plateaus, though no remnants of those are to be recognized within its boundaries. The elevations range from just above 800 feet on Buffalo Creek to nearly 4,400 feet in the southeast corner. The region, as a whole, is deeply incised, the hills rising from 500 to 1,000 feet or more above the adjacent streams. There are two rather distinct types of topography found here. The first occurs in two areas, one south of Gauley River and the other north of the divide between Gauley and Elk rivers. In these areas the streams occupy relatively narrow valleys between steep banks, rising to rounded divides. As a rule, the valleys are too narrow to pay for cultivation, and nearly all of the farming is upon the tops or upper slopes of the ridges, so that the roads usually follow the divides and cross, but do not follow, the valleys. The second type of topography is found between Gauley River and the divide to the waters of Elk River. Within this area the valleys are generally flat and broad with low gradients, separated by divides that are usually narrow and irregular. Here farming is almost entirely confined to the broad, flat valleys. The difference in the two types of topography is due to the positions of certain sandstone strata and the accompanying shale beds.

CULTIVATION.

At present the quadrangle is lacking in railway facilities. As a result there exist within it large tracts of fine timber, which are very sparsely inhabited, only a small portion, confined almost entirely to the ridges in the southern half and the northeast corner, being at

present under cultivation. In the area immediately north of Gauley River the farms are in the valleys or on the broad benches. At the present time a branch of the Baltimore and Ohio Railroad extends into the area to Richwood, and there are prospects that in the near future other railroads will be built for the exploitation primarily of the timber and later of the coal.

DRAINAGE.

Gauley River crosses the quadrangle in almost an east-west direction near its center and drains most of it. The drainage of the north edge is to Elk River, mainly through Birch River and Buffalo Creek. Meadow River is the main tributary of the Gauley from the south in the western part, while the Cherry and the Cranberry are the principal tributaries in the eastern part of the area. The extreme southwest corner drains to New River. As a rule, the streams have a rapid fall and during much of the year are clear, and at the present time (before extensive lumbering has been undertaken) are among the most attractive streams in the Appalachian Mountains. As the water comes entirely from sandstone and shale, it is what is commonly known as freestone, or soft water.

GEOLOGY.

The rocks of this quadrangle belong almost entirely to the Pottsville group of the Pennsylvanian series of the Carboniferous. The rocks are predominantly sandstones or sandy shales, accompanied by valuable beds of coal and clay. The dip is nearly uniform from southeast to northwest, ranging from almost nothing to 300 or 400 feet to the mile, with an average of from 100 to 200 feet.

WATER RESOURCES.

Water for domestic purposes.—At present wells are mainly depended upon for drinking water and other domestic purposes. Over a large part of the area the houses upon the ridges depend upon wells rather than upon springs because of the necessary distance down to the latter. Such wells are usually not deep and get but a variable supply. In very dry weather they tend to give out, and recourse is had to the springs down the slopes of the hills. In the flat valleys and on the broad benches north of Gauley River wells are also depended upon. Summersville, the county seat of Nicholas County, and until a few years ago the largest village within the area, depends entirely upon wells. Richwood, which has recently sprung up on the branch of the Baltimore and Ohio Railroad, is supplied from several deep driven wells and has a waterworks system. Farms which are

on the slopes of the hills or in the narrow valleys south of the Gauley usually depend upon springs. No large springs were noted in this area, but small springs are abundant, especially at the horizons of certain of the coals. One coal, known as the "Gauley," which is found at or near the horizon of the well-known Sewell coal on New River, is a notable spring horizon. From the almost uniform dip of the rocks it would seem that this area offers unusual opportunity for developing artesian wells.

Water power.—The large percentage of the ground that is covered with standing timber tends to render the streams fairly constant in volume. Most of them have a small flow all through the summer, even in extremely dry weather. On account of the narrowness of most of the valleys the latter are of very limited value for farming purposes, and the dip of the rocks carries many hard cliff-making sandstones down to water level along many of these valleys, rendering possible the construction of large power dams at relatively small cost. Probably a large percentage of the streams could be dammed at some point so as to yield a fair amount of power, which could be transmitted electrically to some manufacturing center.

In many cases where the streams cross the sandstones falls or rapids are produced, among which may be mentioned the falls of Hominy and Grassy creeks, each of which is about 20 feet high. North of Gauley River the streams cross a sandstone which lies just below the level of the flat bottom lands and then cut through a comparatively deep gorge to the Gauley. Most of these streams present opportunities for water storage and power.

WATER RESOURCES OF THE MINERAL POINT QUADRANGLE, WISCONSIN.

By U. S. Grant.

LOCATION AND GENERAL RESOURCES.

The Mineral Point quadrangle is situated in the southwestern part of Wisconsin, with its southern edge extending less than one-half mile into Illinois. It comprises considerable parts of Iowa and Lafayette counties and the eastern portion of Grant County, in Wisconsin, also a narrow strip along the northern border of Jo Daviess County, Ill. The quadrangle is bounded by west longitude 90° and 90° 30′ and by north latitude 42° 30′ and 43°, and contains, approximately, 878 square miles.

The district is one which was settled early in the history of Wisconsin, and is a rich agricultural region. The chief farm products are hay, corn, oats, cattle, butter, and cheese. There are small manufacturing establishments at a number of points, and at the town of Mineral Point large quantities of sulphuric acid and zinc oxide are produced.

The district is in the heart of the upper Mississippi Valley lead and zinc region, and has for seventy-five years been known as a producer of lead and zinc ores. During recent years this production has decreased, but in the past two or three years the production of zinc ore has advanced markedly. This is due to the mining of bodies of zinc sulphide which exist below the level of ground water, a horizon below which much of the early mining did not extend. The prospects are that the future will see a more extensive development of this mining industry and that the district will continue to be an important area for both metals.

The principal towns are Platteville, Mineral Point, Dodgeville, Darlington, and Shullsburg. The district is reached by branch lines of the Chicago and Northwestern Railway, the Chicago, Milwaukee and St. Paul Railway, and the Illinois Central Railway.

TOPOGRAPHY.

The Mineral Point quadrangle is situated within the driftless area of upper Mississippi Valley, a region which was not crossed by the invasions of the Pleistocene ice sheets, and consequently lacks those peculiar details of topography which are so common in the surrounding glaciated areas. Thus there are none of the minor irregularities due to drift deposits, nor are there lakes or swampy areas except locally along the flood plains of some of the larger streams, and the drainage features are well developed and systematized. In fact, the whole topography is that produced by subaerial erosion acting on strata nearly horizontal in position and of rather uniform degrees of resistance.

The most noticeable topographic feature of the district is the flatness of the uplands, for from any of the stream divides in the district the eye passes over an apparently even stretch of land. In this plain the streams have cut marked valleys, the main ones of which lie 200 feet or more below the main level. These valleys are wide and flat-bottomed, even when very small, and the district is topographically mature. It has been estimated that about one-half of the cubic contents of the land for 300 feet below the surface of the plain has been carried away by stream erosion. Above this level, which is of the nature of a peneplain formed probably in Tertiary time, rise two groups of isolated mounds or monadnocks, one group (the Platte mounds) lying 5 miles northeast of Platteville and the other south of Shullsburg.

Aside from the mounds, the highest of which rises 1,430 feet above the sea, the most elevated points of the plain are near the north side of the quadrangle along what is known as the Military Ridge, where the altitude averages close to 1,200 feet above sea level. To the north of this ridge the streams descend rapidly, and the land less rapidly, to Wisconsin River, which is outside of the boundary of the quadrangle. To the south the plain slopes gradually toward the south-southwest, the lowest point being near the southwest corner of the quadrangle, or about 950 feet above sea level. The lowest point in the valleys—660 feet above tide—is along Fever River, where it crosses the southern boundary of the quadrangle. The difference between the extremes in elevation in the quadrangle is 770 feet.

GEOLOGY.

The district is underlain by rocks of early Paleozoic age, which dip at very low angles toward the south-southwest, but in some places have been thrown into gentle folds whose axes have a general east-west direction and whose south limbs are long and gently sloping,

while their north limbs are short and steeper. The formations represented in the district are shown in the following table, in which the approximate average thickness of each is given:

Ideal section in Mineral Point quadrangle.

		Feet.
Quaternary	Loess and soil	7
Silurian	Niagara limestone	50
Ordovician	Maquoketa shale	160
	Galena limestone	230
	Platteville limestone	55
	St. Peter sandstone	70
	Lower Magnesian limestone	200
Cambrian	Potsdam sandstone	700

The Potsdam sandstone does not outcrop within the area of the quadrangle, but is regarded as present beneath the Lower Magnesian limestone over the entire district. The Lower Magnesian limestone consists of a lower main body of massive dolomite, above which is a sandstone layer which is usually overlain by another dolomite. The outcrops of the Lower Magnesian in this quadrangle are confined to the bottoms of some of the valleys, where it emerges irregularly from beneath the overlying St. Peter sandstone. The St. Peter sandstone is usually a poorly cemented, comparatively pure quartz sandstone. It varies considerably in thickness and its outcrops are confined to the valleys. The Platteville (or Trenton) limestone is, except for its lower part (which is magnesian), a true limestone, which, for this reason and also because it commonly occurs in beds of only a few inches in thickness, is readily distinguished from the other limestone formations of the district. It outcrops along the sides of many of the valleys. The Galena limestone is a massive, rough-weathering, frequently flinty dolomite, which forms the surface rock over the main part of the quadrangle. Outcrops are frequent. In this formation and in the upper part of the next lower are the lead and zinc deposits of the district. The Maquoketa shales (frequently called in this district the "Hudson River" shales) consist of blue to green shales and clays, with some thin bands of earthy limestone. This formation, because of its soft nature, is rarely seen in outcrop. It is confined chiefly to the base of the mounds and to some of the higher ground surrounding the mounds. The Niagara limestone is a dolomite, frequently carrying large amounts of flint, and is confined to the summits of the higher mounds; its total thickness is not seen in the Mineral Point quadrangle, the figures above given referring only to the formation as here represented. This hard dolomite at times forms bold outcrops near the summits of the mounds.

The soils of the district, except the valley alluvium, are residual—that is, are formed from the decay of the immediately underlying

rock. Spread over much of the district is a very thin mantle of loess, which becomes thinner and even entirely lacking in the eastern portion of the quadrangle. It is more noticeable on the west and southwest, but even here it rarely exceeds 4 feet in thickness and does not average more than half of that amount.

These indurated formations represent one long period of early Paleozoic sedimentation twice interrupted—once probably in Potsdam time and again at the end of Lower Magnesian time—the St. Peter sandstone being unconformable upon this limestone formation. There are no evidences in this quadrangle that formations later than the Niagara were deposited here. There is, though, in the peneplain already mentioned, direct evidence that the district was reduced by subaerial erosion to a low-lying, rather level surface, probably in Tertiary time. Later the peneplain was elevated and erosion has continued uninterruptedly to the present day.

WATER RESOURCES.

SPRINGS.

Among the important water resources of this quadrangle are springs, which are numerous, and which are in the main confined to three geologic horizons—the base of the Galena limestone, the base of the Platteville limestone, and the base of the St. Peter sandstone. A few springs issue at other horizons, as on shaly layers in the Galena, but these are not large and do not occur uniformly.

At the base of the Galena is a stratum, from a few inches to 4 feet in thickness, of a black to brown carbonaceous shale, which is known locally as the oil rock. This is commonly underlain by one or more thin strata of blue to white clay or shale. All these strata are practically impervious and turn much of the water which soaks down through the porous Galena dolomite above. Springs from this horizon are less common in the eastern portion of the quadrangle than elsewhere, although they do occur here, while they are common wherever streams have cut down into the Platteville limestone in the vicinity of Platteville.

Immediately overlying the St. Peter sandstone is a bed of blue shale, sometimes sandy, which is from 2 inches to 3 feet in thickness. This very commonly turns the water, and there results the rather unusual phenomenon of a marked line of springs above a porous sandstone formation. This is a very constant spring horizon throughout the parts of the district in which the St. Peter sandstone outcrops.

The Lower Magnesian limestone appears irregularly beneath the St. Peter sandstone in some of the deeper valleys. Close to the top of this limestone formation at times are beds of very compact lime-

stone or of shale and clay. The springs at this horizon are not so numerous nor so constant in occurrence as at either of the two other horizons.

These springs frequently form the starting points of permanent streams, and they are of local importance to the farmers, as they furnish fine supplies of water for domestic and dairy uses, thus frequently determining the location of the farm houses.

STREAMS AND WATER POWERS.

The rainfall of the district is approximately 35 inches a year, the streams are numerous, and irrigation is not necessary. The smaller streams of the quadrangle descend quite rapidly, at times as much as 60 feet per mile, while the larger streams have in their lower parts an average descent of not to exceed 10 feet in a mile. There are no waterfalls in the quadrangle, except those altogether too small to be utilized as water powers. The main streams are Pecatonica River in the eastern and Fever River in the southwestern part. Both streams head within the quadrangle. The former is the larger, but both are capable of furnishing water power for local use, though at present they are not utilized except at two points—at Darlington, on Pecatonica River, and near Benton, on Fever River, where small dams have been erected. Many of the streams of the district having a fall of from 10 to 40 feet per mile possess enough volume to furnish water powers sufficient for small flour and grist mills. Abandoned mills and millraces testify to the use of these water powers before the building up of the large milling centers in the Northwest.

WELLS TO GROUND WATER.

The distance from the surface to the level of ground water in this area varies from less than 10 feet in the valleys to 100 feet or more on some of the high interstream areas. No figures are available as to the average depth to the ground-water level, but this is far enough below the surface to make it usually inexpedient to excavate open dug wells. Wells sunk by churn drill are common, especially in the broad upland parts of the district. The Galena limestone, which is the rock immediately underlying the surface in the greater part of the quadrangle, is sufficiently porous to furnish reasonable supplies for domestic purposes in wells sunk a few feet below ground-water level. The water of such wells is somewhat hard (although no accurate determinations are at hand), but of excellent quality for domestic use. Where wells are sunk to ground-water level in areas underlain by the St. Peter sandstone the supplies of water are large.

DEEP WELLS.

For deep wells there are two important water-bearing horizons, the Potsdam and the St. Peter sandstones, one or both of which can be found under all the quadrangle. Little can be said concerning water supply from the sandstone in the upper part of the Lower Magnesian limestone, for it is not yet known whether it extends under all the quadrangle, and in some places it is not separated from the St. Peter by marked limestone strata.

St. Peter sandstone.—The St. Peter is a poorly cemented homogeneous sandstone of medium grain, composed sometimes of 99 per cent of rounded quartz grains. It is an ideal water-bearing stratum. Near the northeast corner of the quadrangle its upper surface is 1,050 feet and at the southwest corner about 600 feet above sea level. It may be regarded as descending uniformly from the former to the latter altitude, except for two areas, where it is 50 to 150 feet higher than normal. These areas are along gentle anticlinal folds whose axes run east and west; the axis of one fold lies south of Mineral Point and north of Platteville, and that of the other runs from Redrock on the east to Cuba on the west. In the general upland level (the old peneplain surface) of the quadrangle, where the Galena is the surface rock, the St. Peter can be reached in from 100 to 300 feet, while in areas immediately underlain by Maquoketa shales (as about the Platte mounds, near Hazel Green, and south of Shullsburg) it is farther from the surface. Wells sunk into the upper part of this sandstone will at times furnish good supplies of water, while an abundant supply can be counted on, except near some of the Lower Magnesian outcrops, in wells sunk to the base of the St. Peter. The water from this sandstone is less liable to hold considerable quantities of mineral substances than is water from lower horizons.

The inclination of the strata is toward the south-southwest, the dip being greater than the surface slope. Thus favorable conditions for artesian flows from the St. Peter sandstone would exist in the southern part of the quadrangle were it not that toward the south (at La Salle and Oregon, Ill.) and the west (near Dubuque) this sandstone outcrops at lower levels than it holds within the quadrangle. So artesian flows are not to be expected from this water-bearing stratum, though in some wells the water will rise for a short distance above the top of the sandstone.

Potsdam sandstone.—The Potsdam sandstone is in large part as uncemented as the St. Peter, and so is a good water-bearing formation. It has, however, commonly more calcareous and argillaceous impurities, which at times form distinct limestone and shale beds, and thus furnishes more than one water-bearing horizon. The Potsdam un-

doubtedly underlies the whole quadrangle at a depth of from 230 to 350 feet below the top of the St. Peter. It can be relied upon as a strong water-bearing formation, and is even more important than the St. Peter. Water from the Potsdam will rise above the top of that horizon, but can not be commonly expected to furnish flowing wells. It is, however, possible that flowing wells from this horizon may be obtained in some of the valley bottoms.

WATER RESOURCES OF THE JOPLIN DISTRICT, MISSOURI-KANSAS.

By W. S. Tangier Smith.

TOPOGRAPHIC AND GEOLOGIC CONDITIONS.

LOCATION.

The Joplin district is located at the intersection of the boundary lines of Missouri, Kansas, and Indian Territory. It embraces an area of 476 square miles, lying between 94° 15′ and 94° 45′ west longitude and 37° and 37° 15′ north latitude. About three-fourths of the district lies in Missouri, and includes among its larger towns Joplin, Webb City, and Carthage; the remaining fourth (except for a fraction of a square mile falling in Indian Territory) is in Kansas, and its largest towns are Galena, Empire, and Baxter Springs. It is essentially a lead- and zinc-mining region, and most of the settlements of the district are dependent on these interests. Next to mining, agriculture is the most important industry.

TOPOGRAPHY.

The Joplin district lies near the western margin of the Ozark uplift, a flat, asymmetric dome comprising most of the southern half of Missouri and the northern half of Arkansas. The upland surface of the district is almost flat, with a very low general slope to the northwest. These nearly level uplands—on which most of the cities and towns are located—are cut by numerous stream valleys, for the most part open and rather shallow. The valleys grow deeper toward the southern and western parts of the quadrangle, reaching a maximum depth of about 200 feet below the adjacent uplands, and bordered here and there, especially along Shoal Creek, by abrupt cliffs. The drainage of the district as a whole is toward the southwest.

DRAINAGE.

The most important drainage lines of the district are Spring River and its tributaries, Shoal, Center, Turkey, Cow, Shawnee, and Short

creeks and Buck Branch, together with several of the tributaries of Center Creek. These, with about two dozen minor streams, comprise all the perennially flowing streams of the district. The minor drainage lines run for the most part roughly at right angles to the valleys to which they are tributary, and are characteristically short, seldom exceeding a length of 3 or 4 miles. None of the streams are navigable. Even the largest, Spring River and Shoal Creek, though comparatively broad—the former having a width of 150 feet or more in places along its lower stretches—are at many points shallow enough to be forded.

The streams are all spring fed (except for a few small ones formed by water pumped from the mines), and those which rise outside the district receive important additions from springs in their course across it.

GEOLOGY.

The rocks of the district are wholly sedimentary, and the surface exposures are all of Carboniferous age, both the upper and lower being represented. The lower Carboniferous (Mississippian) rocks consist of about 350 feet of normally nonmagnesian limestones and cherts in varying proportion, constituting the Boone formation. Not far from the top of this formation is a thin but persistent bed of oolite, outcrops of which occur in all parts of the district. About 100 feet below this is a heavy bed of chert, averaging about 40 feet in thickness and known as the Grand Falls chert.

The exposures of the Mississippian rocks cover the greater part of the Joplin district. Above these lie the upper Carboniferous (Pennsylvanian) shales and sandstones, constituting the Cherokee formation. There is a considerable area of these shales and sandstones along the western margin of the quadrangle west of Spring River, in addition to which scattered areas and patches of them dot the entire district.

As shown by exposures outside the district and by deep drill holes, there is beneath the Mississippian rocks a very thin body of Devono-Carboniferous deposits, succeeded in depth by 1,300 or 1,400 feet of Cambro-Silurian rocks, consisting of a series of dolomites, magnesian limestones, and sandstones, chiefly the first. These overlie the pre-Cambrian crystalline rocks.

The rocks of the district have a low general dip to the northwest, at an angle somewhat greater than the general inclination of the surface. Open folding is common on both a large and a small scale. Noticeable faulting is uncommon over the quadrangle as a whole, but in those parts where the lead and zinc deposits occur both faulting and folding are of more importance. The faulting has often

given rise to brecciation of the rocks adjacent to the fault planes, especially in the more cherty portions of the Boone formation. The underground waters of the district, as seen in springs and deep wells and in the mines, circulate chiefly along the bedding planes of the rocks and along the fault planes—at least within the Boone formation—the chert breccias forming unusually favorable channels for underground circulation.

WATER RESOURCES.

The economic water supply of the district is drawn from the streams, springs, wells, and rainfall, the last being sufficient in general for agricultural purposes.

STREAMS.

General character.—The streams of the district are used both as a source of water supply and for power. Of those available for power Shoal Creek has an average fall of 7 feet to the mile for the 17 miles of its course through the district. Center Creek has an average fall of 6.3 feet per mile for its 27 miles, while the average fall of Spring River for the 28 miles of its course included in the western part of the district is only 2.1 feet to the mile, and for its entire length within the district about 3.6 feet per mile. The grade of these streams is somewhat variable, so that locally the fall is considerably greater than the figures given. At Lowell the course of Spring River is broken by rapids, while along Shoal Creek between Lowell and Reddings Mill rapids are found at a number of points. The only falls on these streams are those at Grand Falls, on Shoal Creek.

Power.—Shoal Creek has been dammed at Reddings Mill and at Grand Falls, furnishing power at the former for a mill on the south bank of the stream and at Grand Falls for the Joplin electric-light plant. At Lowell, which is situated at the mouth of Shoal Creek, both this stream and Spring River are dammed, the former stream furnishing power for a gristmill which has not been run for two years or more. The water of Spring River is used here for a large gristmill on the west side of the river and for a small corn and feed mill on the east side. On account of the low grade of the stream the dam across Spring River here backs the water for about 2 miles up the river. Below Lowell and east of Baxter Springs Spring River is dammed again to furnish the power for a large mill.

Up Spring River from Lowell there was formerly a mill using water power, at the old Boston Mill Bridge across Spring Creek north of the mouth of Center Creek. South of Waco, on Spring River, there is a small mill, which has lately been repaired and put in

running order. In addition to these, there is a mill obtaining power from Spring River 1 mile west of the eastern margin of the district. A short distance south of Spring River, in Carthage, a large mill, which was burned down not long since, had a canal more than three-fourths mile long cut to it from the river. A flour mill near Spring River, west of Alba, also obtains water power from the river through a canal, in this case nearly one-half mile long.

Domestic supply.—Spring River and Center and Shoal creeks furnish the water supply of most of the cities of the district. The Carthage pumping plant is on Spring River just north of the city. The pumping station of the Webb City waterworks is on Center Creek about a mile east of Oronogo. That for the Galena waterworks is on Shoal Creek about 1½ miles south of the city. The Joplin city water is taken from Shoal Creek at a point about 3 miles a little west of south of the city, and about 6 miles east of and above the source of the Galena supply. It is pumped to a settling basin in Blendeville in the southern part of the city, where it is filtered before being pumped into the city mains.

A number of the streams of the district, most of them otherwise potable, have been polluted to a greater or less extent by water pumped from the mines. These waters contain zinc sulphate and other impurities, which, if sufficient in amount, render the streams unfit for domestic uses and sometimes for other purposes as well. Pollution from this source is greatest, of course, immediately in the neighborhood of the mining camps, and it affects chiefly the smaller streams. Rarely the zinc content of the waters is sufficient, as in the case of Turkey Creek, to destroy the fish once found in the stream. Of the larger streams those principally affected are Turkey and Short creeks and, to a much less extent, Center Creek below Carterville and Oronogo. Comparatively few mines contribute water directly to Spring River and Shoal Creek. For this reason and on account of the large volume of these streams, their zinc content is small. In the Joplin city water, taken from Shoal Creek, the amount of metallic zinc, as determined at different times by Mr. W. George Waring, ranges from a trace to 4.2 parts per million.

It is probable that the Galena city water has a somewhat larger proportion of zinc than the Joplin water (though not a dangerous amount), on account of the zinciferous springs and the mines of Gordon Hollow and its neighborhood, which are located just north of Shoal Creek and several miles above the point of intake of Galena's water supply, and on account of the waters from the mines south of Blendsville, which empty into Shoal Creek just below the source of Joplin's city supply. In addition to this there is the danger of sewage pollution from these mining camps. In the case of the Joplin city water any such danger appears to be slight, and it

is doubtless reduced to a minimum by the filtration to which the water is subjected.

The water of Shoal Creek is only slightly turbid, is without odor or appreciable taste, and appears, from partial analyses made by Mr. Waring, to have a low content of mineral matter. The water of Center Creek, as shown by the accompanying analysis, contains a moderate amount of mineral matter, the comparatively large proportion of silica and alumina being due to suspended clays.

Mineral analysis of water from tap in Webb City waterworks office.

[Parts per million.]

Silica	66.4
Alumina	16.9
Sodium chloride	9.6
Sodium sulphate	68.4
Magnesium sulphate	38.3
Ferrous sulphate	10.5
Calcium sulphate	111.5
Calcium bicarbonate	240.9
	557.5

Cleveland and Millar Analytical Laboratory, analyst.

While this water is not known to be contaminated by sewage, the location of Lakeside Park, between 2 and 3 miles above the source of the Webb City supply, suggests a possibility of danger from this source.

The Carthage city water is undoubtedly as free as any of the waters derived from the streams of the district from contamination from any source.

SPRINGS.

Occurrence.—Springs are common throughout the district, especially along Shoal Creek and its tributary valleys. They are found for the most part along the margins of the valleys, though one issues on the upland west of Joplin, the water here rising to the surface along a fault plane. These waters come from different horizons in the Boone formation. The Grand Falls chert appears to be especially favorable to underground flow, and many of the springs along Shoal Creek (almost the only part of the district where this member of the Boone formation is exposed) emerge at either its upper or lower surface. The springs are often of considerable volume, but the amount of flow has not been definitely determined in any instance. The largest one known to the writer in the district—on the eastern margin of Grove Creek valley, about one-half mile west of north of Scotland—gives rise to a stream 12 feet wide and 6 or 8 inches deep.

Character.—The water from all the springs is cold, no thermal springs being known in the district. Most of the spring waters are clear, colorless, without sediment, and are potable, containing only a

comparatively small amount of mineral matter in solution, chiefly calcium bicarbonate. Analysis No. 1 of the accompanying table is probably typical of these springs. Where favorably situated these springs are used as a source of water supply for household and other purposes, but not for irrigation, so far as known. The water from the spring on the upland west of Joplin is not only used by the people of the vicinity, but is also piped to a neighboring mine.

Of the comparatively few spring waters of the district which differ from those just referred to, one (see analysis No. 2) contains sodium sulphate (which, next to calcium bicarbonate, is its principal constituent) in sufficient amount to be somewhat medicinal, thus classing it as a mineral water. The chalybeate springs at Baxter Springs—used commercially and as a resort—contain chiefly calcium and iron bicarbonate (analysis No. 3). These waters have only a slight taste and show a slight reddish, flocculent precipitate.

A few of the springs of the district contain, in addition to the constituents usually found in such waters, more or less zinc derived from the oxidation of neighboring deposits of zinc ore. Springs apparently normal in other respects are thus rendered unfit for use. This applies particularly to the springs in and near Jackson, Roaring Spring, and Gordon hollows, most of which form more or less of a cream-colored to nearly white, flocculent deposit. All the waters showing these deposits probably contain zinc, which is known to occur in four of the springs. One near the head of Roaring Spring Hollow, according to an analysis by Mr. W. George Waring, contains 102.8 parts per million, while two springs nearly a mile south of east of the mouth of Gordon Hollow, and just north of Shoal Creek (see analyses Nos. 4 and 5), contain, respectively, 120.5 and 132.4 parts per million of zinc. The deposits of these springs, as shown by qualitative analyses, differ somewhat in character from each other, though in most cases they appear to consist chiefly of alumina and aluminum sulphate, together with more or less silica. Some of the deposits contain zinc, but others do not, even where it is present in the water itself, as in that analyzed by Mr. Waring. The waters analyzed by Doctor Hillebrand were considered by him unique in having zinc sulphate as their chief constituent. These waters have a more or less astringent taste, only slightly so in some cases. Near the mouth of Gordon Hollow is a spring the water of which is clear, the only deposit formed being an ocher-yellow film on rock surfaces over which it flows. This water has an astringent, alum-like taste, and gives an acid reaction with litmus. Other springs containing zinc are the Great Western, nearly 3 miles north of east of Joplin, and the Green spring, east of Empire, which are shown by analyses to contain, respectively, 35 parts per million and 12.6 parts per million of metallic zinc.

Analyses of spring waters.

[Parts per million.]

	1.	2.	3.	4.	5.
Lead sulphate	None.			Trace.	
Copper sulphate	Trace.			0.5	
Cadmium sulphate				.9	
Zinc sulphate	None.			297.7	327
Ferrous sulphate		1.8		1.6	1.6
Manganese sulphate				6.3	6.6
Aluminum sulphate				2.5	3.2
Barium sulphate	None.				
Calcium sulphate		49	66.2	109.9	85.8
Magnesium sulphate	0.4	11	11.7	19	21
Sodium sulphate	4	204.4		5.9	6.8
Potassium sulphate	2.2			5.6	5.6
Sodium chloride	2.8	13.3	3.4	4.3	4.3
Potassium chloride			1.9		
Ferrous carbonate			92.1		
Ferrous bicarbonate	Trace.				
Calcium carbonate			152.5	72	94.7
Calcium bicarbonate	172.7	369.4			
Magnesium carbonate			2		
Magnesium bicarbonate	14.6				
Lithium carbonate			6.9		
Carbon dioxide (free)	1.3		([a])		
Silica	15	13.7	39.4	13.7	15.7
Alumina	Trace.	2			
Organic matter, volatile, and loss			29.2		
	213	664.1	405.3	539.9	579.3

[a] 38 cubic inches.

1. Water from spring, eastern margin of Shoal Creek valley, about 3½ miles southeasterly from Thurman. Analyst, H. N. Stokes, U. S. Geological Survey Laboratory. Combination of substances by W. S. T. Smith.
2. Water from spring near Webb City. Analyst, Cleveland and Millar Analytical Laboratory, Joplin.
3. Water from Baxter Springs. Analyst, A. Merrill (1882). Reference: Bull. No. 82, U. S. Geol. Survey, p. 173.
4. East Spring, and 5, West Spring, from group of springs on the road from Joplin to Seneca, about 4½ miles southwest of Joplin, at the base of a low bluff of Grand Falls chert. Analyst, W. F. Hillebrand, U. S. Geol. Survey laboratory. Reference: Am. Jour. Sci., 3d ser., vol. 43, p. 419.

WELLS.

General character.—Shallow dug wells are, outside the cities, the most common source of water supply throughout the district, and are to be found on the outskirts of even some of the larger cities. Such wells range in depth from about 15 to about 65 feet. Some of the deeper wells of the district are also partly dug, only their lower

portions being bored. Occasionally water in old prospect or mine shafts is utilized as a source of local supply, when it is not contaminated by oxidation products from the ore deposits.

Deep wells.—There are in the district several thousand drill holes, nearly all sunk in search of ore, and ranging from slight depths to 600 feet or more, very few, however, exceeding 250 feet. Although for the most part concentrated in the mining camps, scattered holes are to be found in all parts of the district, and in some instances, outside the mining camps, they have been utilized as deep wells. In the vicinity of the mines, however, they are not in general available for this purpose, on account of the lowering of the water level by pumping at the mines, and also because of the frequent contamination of the waters by oxidation products from the ores. Probably none of the holes which are less than 300 feet deep extend below the base of the Boone formation. In addition to these, between twenty and thirty deep drill holes have been put down primarily for water to depths ranging from about 500 to 2,005 feet. They are, with one exception, the result of private enterprise, and a considerable proportion of them have been sunk chiefly to obtain water for use in boilers. Besides this use, the water from the wells is employed for making ice and for other commercial purposes, as well as for domestic use. In Joplin and Webb City, although both have a regular water supply, water from deep wells is carried about in water carts and sold for drinking. Empire is the only town depending on a deep well for its water supply.

There are no flowing wells, the water standing at depths ranging from 15 to 200 feet below the surface. Both lift pumps and compressed air are used for raising the water. The full capacity of most of the wells is not known. The Missouri Lead and Zinc Company's well at Joplin has a capacity of about 4,000 gallons per hour (68 gallons per minute). In other instances water has been pumped in amounts ranging from 2,000 to 12,500 gallons per hour without affecting the level. Except close to the surface the ground is, in general, firm enough to stand without caving. A part of the wells, at least, are cased, the casing in several known instances extending to a depth of 400 feet. The water in the wells is, in general, derived from the Cambro-Silurian rocks, although there do not appear to be in these rocks any definite water-yielding beds which are continuous throughout the district. In some instances, as the Redell well in Joplin, there is but one flow of water, in this case at a depth of 1,350 feet; in others there are several flows. At the Freeman Foundry well, less than three-fourths mile south of the Redell well, water was struck at depths of 815, 860, 875, and 900 feet, the chief flow being from the uppermost horizon.

The catchment area for these deep wells is to the southeast, where the northwesterly dip of the rocks brings the deeper formations of the district successively to the surface. It extends at least as far east as the crest of the Ozark uplift, and probably some distance beyond it.

Chemical content.—The water from these wells is moderately cold, temperature determinations in three cases ranging from 63° to 66½° F. The water in three of the Joplin deep wells has a slight though distinct odor of hydrogen sulphide as it issues from the well, and this is probably true also of some of the others of the district. This odor disappears after the water has stood for a while, and it is not enough to give the water any taste. Chemically the well waters which have been analyzed show considerable uniformity. As shown by the following table, the total content of mineral matter is low, consisting chiefly of calcium and magnesium bicarbonates, with smaller amounts of sodium and potassium salts and silica.

Analyses of deep-well waters, Joplin district.

	1.	2.	3.	4.	5.	6.
Copper sulphate	Trace.					
Calcium sulphate					6.8	
Magnesium sulphate	13.8					
Sodium sulphate	11.1	51.4	20.6	21.3		1.8
Potassium sulphate	12.5					
Sodium chloride	15.3	11.7	16.6	19.9	9.9	8.2
Potassium chloride		Trace.				
Lithium chloride	Trace.					
Ferrous bicarbonate	1.3	.9	2.6	2.9		.2
Calcium bicarbonate	162.9	214	178.5	150	202.5	215.5
Magnesium bicarbonate	60.1	98.6	131.3	103.7	108.8	43.8
Sodium bicarbonate		14.5	35.6	30.9		74.1
Silica	47.7	7.2	14.2	10		10.8
Silica and insoluble residue					12.5	
Alumina	Trace.			.9		.2
Undetermined					7.7	
	324.7	398.3	399.4	339.6	348.2	354.6

1. Redell well, Joplin. Analyst, H. N. Stokes, U. S. Geol. Survey laboratory; combination of substances by W. S. T. Smith.
2. Freeman Foundry well, Joplin. Analyst, Cleveland and Millar Analytical Laboratory, Joplin.
3. Well on Missouri Lead and Zinc Company's land, Joplin, taken when well was 940 feet deep. Analyst, Cleveland and Millar Analytical Laboratory.
4. Well on Missouri Lead and Zinc Company's land, Joplin, taken when well was 1,387 feet deep. Analyst, Cleveland and Millar Analytical Laboratory.
5. Well on Missouri Zinc Fields Company's land, Webb City. Analyst, W. Geo. Waring, Webb City.
6. Well on American Zinc, Lead and Smelting Company's land, Carterville. Reference: Water-Supply and Irrigation Paper No. 102, U. S. Geol. Survey, 1904, p. 405.

Location.—The locations of the deep wells in the district are as follows:

Carthage: Well at Harrington dairy, just east of the city (2,005 feet in depth, the deepest in the district); Independent Powder Works well (746 feet deep), 3 miles southwest of Carthage.

Webb City: Wells at the ice plant, at the power house of the Southwest Missouri Electric Railroad Company (826 feet deep), and at Harrod Brothers' meat market (825 feet deep).

Wells on mining tracts southeast of Webb City: Center Creek Mining Company (827 feet), Missouri Zinc Fields Company (854 feet), Homestead Lead and Zinc Company (650 feet), American Lead, Zinc and Smelting Company (799 feet), Eleventh Hour Mining Company (1,000 feet), Troup Mining Company (998 feet), and Ten O'Clock Mining Company (537 feet).

Carterville: Well at Bryant's Iron Foundry (643 feet deep).

Duenweg: Boston-Duenweg Zinc Company's land (475 feet deep).

Joplin: Keystone Hotel, G. H. Redell's brewery (1,379 feet), ice plant, Freeman Foundry and Machine Works (908 feet), Missouri Lead and Zinc Company's land (1,387 feet).

Chitwood: United Zinc Companies' land (800 feet).

Galena: Ice plant (972 feet); a second well not used.

Empire: City well (1,002 feet deep) furnishes water for town supply.

WATER RESOURCES OF THE WINSLOW QUADRANGLE, ARKANSAS.

By A. H. Purdue.

LOCATION AND AREA.

The area included within the Winslow quadrangle lies mainly in the western part of Arkansas. Its southern border is but a short distance north of Arkansas River, and its northern border is 4 miles south of the city of Fayetteville. Its boundaries are the parallels 35° 30′ and 36° north latitude and the meridians 94° and 94° 30′ west longitude. It is about 28 miles wide from east to west and 34 miles long, covering an area of about 968 square miles. Of this something like 22 square miles is in Indian Territory.

TOPOGRAPHY OF THE AREA.

In the north-south direction the area extends entirely across the highlands known in Arkansas as the Boston Mountains, and includes some of the highest points of that elevation. The northern three-fourths of the area is essentially a plateau with a slightly curved surface, the highest part extending east and west in about the latitude of the town of Winslow. This plateau is deeply cut into by numerous valleys, the main ones of which run north and south. These, with their tributary side ravines, cut the region up into steep-sided hills with tops from 500 to 1,000 feet above the streams below, from which the adjacent hills and valleys present imposing landscapes. The highest of these hills—the one on which the village of Sunset is located—is near the eastern border of the area and is somewhat more than 2,250 feet above sea level.

From the highest part of the region the surface falls off gradually to the south, so that while the southern part is rugged, the maximum elevation along this border is only about 800 feet above sea level.

DRAINAGE.

About one-sixth of the area, located in the northeastern part of the quadrangle, drains northward into White River; the remainder drains into the Arkansas. The water divide extends from the eastern border of the quadrangle through the town of Winslow, and then runs

northward a few miles west of and roughly parallel with the St. Louis and San Francisco Railroad to the north border of the quadrangle.

While the rainfall is considerable, the short distance on either side of the divide to the borders of the area prevents the occurrence of large streams, though there are many that have a constant supply of water, which, when the streams are at low stage, is very clear from filtering from pocket to pocket through the gravel of the stream beds.

The drainage into White River passes northward through Middle Fork and West Fork of White River; that into the Arkansas passes northward and westward through the Illinois and its tributaries, and southward through Lee Creek, Frog Bayou, Mulberry River, and their tributaries.

GEOLOGY.

The rocks of the region are of Carboniferous age, and consist of limestones, sandstones, and shales. The limestones are confined to the northern two-thirds of the area. They outcrop on the hillsides of the north slope of the Boston Mountains, and are exposed in the deepest ravines of the south slope as far south as the latitude of Porter, on the St. Louis and San Francisco Railroad.

An idea of the stratigraphy and structure of the region can be had from fig. 14. The rocks dip gradually to the south, except in the latitude of Porter, where there is a marked east-west monocline with a south dip, causing all the rocks that lie below the Winslow to pass out of sight below that formation.

North of the monocline is a series of east-west faults, which are pronounced in the west half of the quadrangle. The downthrow of these faults, one of which is shown in the section, is on the north side. Also, there is a fault several miles long, with the downthrow on the east side, following the valley of Cove Creek.

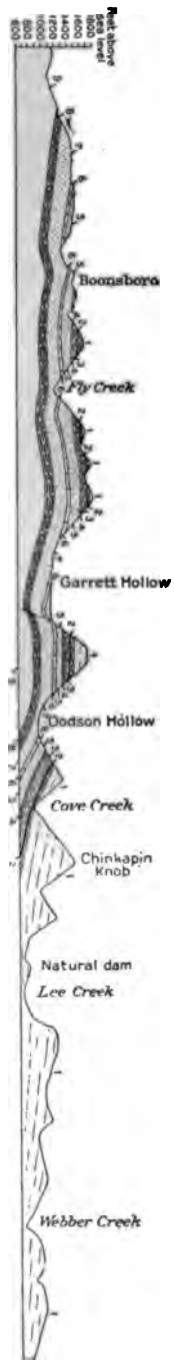

Fig. 14.—North-south geologic section through Boonsboro and Chinkapin Knob, Arkansas. 1, Winslow formation; 2, Kessler limestone; 3, coal-bearing shale; 4, Brentwood limestone; 5, Hale sandstone and limestone; 6, Pitkin limestone; 7, Wedington shale and sandstone; 8, Fayetteville shale; 9, Boone chert.

The following rock formations, named from above downward, occur in the region: Winslow formation, Kessler limestone lentil,

coal-bearing shale, Brentwood limestone, Hale sandstone member, Pitkin limestone, Wedington sandstone, Fayetteville shale, Boone chert.

WATER RESOURCES.

Springs and wells.—Of the above formations, four—the Boone, the Pitkin, the Hale, and the Winslow—are important water producers.

The Boone consists largely of gray limestone, containing a large amount of chert in thin lenses parallel with the beds. This is the surface rock about Prairie Grove and Summers and north of Morrow, in the valley of Prairie Fork of Illinois River. Its presence beneath can usually be determined by the occurrence of loose chert fragments on the surface. Both the chert and the limestone of this formation are much fractured and jointed, making it an easy matter for water to gain access to and pass through it. As a result this formation contains a large amount of excellent water; but because of the level character of the region over which it is the surface rock, only a few springs emerge from it, and in order to secure water it is necessary to sink wells. In the town of Prairie Grove is an excellent spring from this formation, and there is another 1½ miles east of the town.

The Pitkin is a gray, compact limestone from 15 to 40 feet thick, resting upon a bed of shale. It outcrops all along the north slope of the Boston Mountains and in the deepest valleys of the south slope in the western half of the area. The shale beneath holds the ground water up in the limestone, through which it moves along the joints as small, underground streams, and issues here and there in strong, beautiful springs. The springs at Boonsboro come from this limestone, and there are numerous others along its northern outcrop. Likewise there are many springs flowing from this horizon on the south slope where it is exposed in the ravines, such as Cove Creek, Low Hollow, Garrett Hollow, Whitzen Hollow, and Mountain Fork.

The Hale sandstone consists of about 100 feet of calcareous sandstone interbedded with limestone. The sandstone usually contains a great many cavities the size of hen's eggs and smaller. Like the Pitkin, this formation outcrops all along the north slope of the Boston Mountains and in the deep ravines of the south slope. Being thick and of an open, porous nature, it forms an excellent water reservoir, from which a large number of fine springs issue at frequent intervals along its outcrop.

The Winslow formation, which occupies the tops of the Boston Mountains, and is the surface rock over nearly all the south half of the quadrangle, consists of several hundred feet of alternating beds of sandstone and shale. Springs occur on the hillsides of the north slope, but they are of minor importance, both in size and number.

However, the Winslow sandstone furnishes water in abundance from wells of moderate depth, even on the summits of the highest hills. Over the area where this is the surface rock wells are relied on almost wholly for culinary and drinking purposes. In the ravines of the south slope occasional springs issue from sandstone, which owe their existence to the general south dip of the rocks. Of such are Dripping Springs, at Stattler; Oliver Spring, 2 miles west of Rudy; the spring at Dean Spring; Fine Springs in sec. 18 and a spring in sec. 8, both of T. 10 N., R. 30 W.; springs in secs. 17 and 33, T. 12 N., R. 29 W.; springs in secs. 2, 13, 14, and 15, T. 11 N., R. 29 W.; a spring in sec. 33, T. 12 N., R. 31 W.; and one in sec. 11, T. 10 N., R. 31 W.

Nature of the water.—All the water from the limestone beds is clear, cold, and sparkling, and is unsurpassed in purity among natural waters. As would be expected, that issuing from the Pitkin limestone is hard, being heavily charged with lime. That from the Boone chert and the Hale formations, while hard, does not contain as much lime as that from the Pitkin, owing to the large amount of silica in these formations, in the one case as chert and in the other as sandstone. The water in the Winslow formation is soft, coming as it does from sandstone.

Mineral springs.—In sec. 32, T. 11 N., R. 32 W., 1½ miles northeast of Uniontown, is a spring strong in sulphur, which has been inclosed and is locally used for medicinal purposes. It issues from the Winslow. At Sulphur City, in the northeastern part of the quadrangle, a spring of similar nature issues from the Wedington formation and gives rise to a local resort. So far as the writer knows, no analysis of either of these springs has ever been made.

Uses of the water.—The city of Fayetteville receives its water supply from West Fork of White River, the water being pumped 2 miles into a reservoir on a hillside overlooking the place. Aside from this, practically no use is made of the water of the area except for domestic and stock purposes. The gradient of the streams is considerable, and in some places power might be secured to run small mills, but it is not so utilized, probably owing to the fact that it could not be relied upon during the low water.

The southern part of Frog Bayou valley is coming to be generally utilized for the culture of fruit and vegetables, and it appears wholly practicable for the water of that stream to be used for irrigation purposes, thus insuring the crops against droughts, which are not infrequent. Even during seasons of average rainfall, such use of the water would yield sufficient returns in the way of increased production and improved quality of fruit to justify the expenditure for irrigation ditches. The same could be said of the valley of Lee Creek, were it supplied with transportation facilities.

WATER RESOURCES OF THE CONTACT REGION BETWEEN THE PALEOZOIC AND MISSISSIPPI EMBAYMENT DEPOSITS IN NORTHERN ARKANSAS.

By A. H. Purdue.

GENERAL STATEMENT.

The area treated in this paper consists of a belt of land from 12 to 15 miles wide lying along the western border of the lowlands north of Arkansas River and also of a narrow belt of the highlands adjacent.

The field work was done in August and the early part of September, 1903. The object was to map the contact between the highlands and the lowlands in that part of Arkansas north of Arkansas River, ascertain the stratigraphic relations between the rocks of the two areas, determine the water horizons and the sources of water in each, and solve such other economic questions as the depth, amount, permanency, and character of the water.

The work was less thorough than is to be desired, made so by the short time at command, the want of good maps, the uncertain location of the roads in the forest-covered portion, the sparse population of some parts, and the fact that much of the population consists of tenants who are unable to give the necessary land descriptions to enable one to map with accuracy. For these reasons future workers may change somewhat the mapping of the contact between the Paleozoic and Tertiary areas. However, such inaccuracies as may exist are but small ones, and the mapping herein presented can be taken as correct for all practical purposes.

GEOGRAPHIC FEATURES.

TOPOGRAPHY OF THE LOWLANDS.

The lowlands of Arkansas lie in the eastern and southern parts of the State and comprise about half its area. They are a part of a lowland area of vast extent lying within the Gulf States and reaching northward to a point a short distance beyond the junction of Ohio

and Mississippi rivers. The region they cover is known to geologists as the "Embayment Area," and represents the extent of the Gulf of Mexico during Tertiary times.

An idea of the hypsometry of the lowlands may be obtained from the following table of elevations along the St. Louis, Iron Mountain and Southern R "way, beginning at the northern border of the State and extending southward to Arkansas River.[a] In the preparation of this table the railway line "was tied up and adjusted to the line of precise level brought up from the Gulf of Mexico by the United States Coast and Geodetic Survey."

Elevations along St. Louis, Iron Mountain and Southern Railway, Arkansas.

Station.	Elevation.	Station.	Elevation.
Moark	297.10	Grandglaise	223.10
Corning	289.10	Bradford	241.10
Colony Lake	282.60	Russell	233.10
Black River	288.10	Bald Knob	220.10
Knoble	280.10	Judsonia	217.10
Peach Orchard	285.10	Little Red River	217.10
Delaplaine	277.60	Kensett	224.10
O'Kean	270.60	Higginson	220.10
Murtha	270.60	Garner	220.60
Walnut Ridge	270.10	Beebe	244.60
Hoxie	268.10	Ward	238.10
Minturn	260.60	Austin	248.10
Alicia	253.60	Cabot	288.10
Swifton	248.00	Holland	255.10
Tuckerman	241.60	Jacksonville	282.10
Diaz	230.10	McAlmont	271.00
Newport	[a] 227.10	Baring Cross	260.10
White River bridge	232.70	Arkansas River bridge	267.10
Olyphant	220.10		

[a] The track has been raised at Newport, but it is not known how much. Levels from the United States bench mark on the river bank 400 feet north of the elevator make the top of the rail opposite the end of the passenger station 233.07.

It will be seen from an inspection of this table that the elevation of the surface is remarkably uniform. The average elevation of all the stations given is 261.18 feet; that of the highest, Moark, is 297.10 feet; that of the lowest, Judsonia, is 217.10 feet. Notwithstanding this close approach to a uniformity of level, this line, if taken alone, would give an exaggerated idea of the topography of the region, for,

[a] From Ann. Rept. Geol. Survey Arkansas, 1891, vol. 11, pp. 103–104.

running as it does near the contact of the lowlands with the highlands, it varies more from uniformity than would be the case along a north-south line farther eastward. Taken as a whole, there is a slight but gradual fall of the region from the north toward the south, and in the southern part of it from the west toward the east. The small irregularities of the surface that are usually met with are such as have resulted from the formation of natural levees along the overflowing streams and the meandering of such streams.

The only place within the region where there is any approach to marked topographic features is in the southern part, where there is

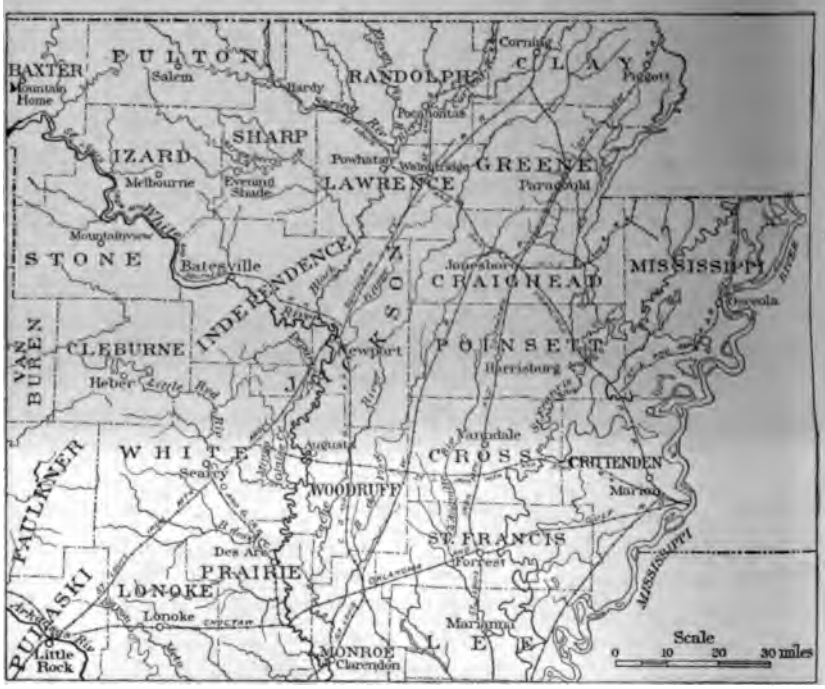

FIG. 15.—Drainage map of northeastern Arkansas.

a small area of irregular outline a mile east of Jacksonville. North of this, and separated from it by Bayou Two Prairie, is a larger area of the same sort, about 10 miles in length and averaging 2 in width, the northern end being just east of the town of Austin. Each of these elevations is about 350 feet above sea level, or 100 feet higher than the surrounding country.

TOPOGRAPHY OF THE HIGHLANDS.

In marked contrast to the monotonous level of the lowlands is the rugged topography of the adjacent highlands. For the purpose of description this will be considered in two parts—that north and that

A. BLACK RIVER AT BLACKROCK, ARK.

A typical stream of the Paleozoic highlands.

B. A TYPICAL STREAM OF THE LOWLANDS.

south of White River. The former is essentially a plain with a maximum elevation of about 400 feet within the area herein considered, dissected by Dota Creek, Bayou Curia, Strawberry River, Eleven Points Creek, Fourche de Mas River, and other small streams debouching upon the lowlands.

The southern part rises quite rapidly from White River to an elevation of about 800 feet above tide, south of Batesville, and then gradually falls off southward as a dissected, sloping plain, to near the latitude of Beebe, southward from which point the plain is succeeded by a series of east-west ridges, in height from 150 to 250 feet above the surrounding country. This region, like the one to the north, is dissected by numerous streams which flow in a general southeasterly direction and pass out upon the lowlands. Among these are Bull Creek, Bayou des Arc, Little Red River, Glaise Creek, Oats Creek, and Departe Creek.

Throughout the entire contact of the highlands with the lowlands, except in small portions of the southern part, the latter abut against an escarpment of the former, so that the line of contact is pronounced. Between the ridges of the southern part the lowlands pass so gradually into the highlands that it is not always an easy matter to determine where to map the contact of the two. But the ridges bounding the valleys are always truncated at the ends, standing up promontory-like, leaving no doubt as to the line of contact.

DRAINAGE OF THE AREA.

The principal stream of the region is White River, which receives from the west Bayou Meto, Bayou des Arc, Little Red River, Glaise Creek, and Departe Creek; from the north, Village Creek and Black River. The latter has two important tributaries—Spring River, emerging from the highland area, and Current River, which flows southward near the contact of the highlands and lowlands.

As would be expected from the low altitude of the lowlands, the valleys therein extend scarcely beyond the stream borders, and the height of the banks above the stream surface seldom exceeds 20 feet, even at low-water stage. (Pls. I, II, and III.)

GEOLOGY OF THE LOWLANDS.

HISTORY.

PRE-TERTIARY CONDITIONS.

The geologic history of the lowlands antedates the period when the Gulf of Mexico covered the Embayment Area. Previous to that time a great valley had been cut into the Paleozoic rocks by

stream erosion, probably aided by faulting.[a] This valley was bounded on the west by the present highlands of Arkansas and Missouri and on the east by the similar highlands of Kentucky and Tennessee, and was several hundred feet deeper than the present surface of the Embayment Area. The edges of the Paleozoic rocks were exposed all around the borders of this old valley, just as their upper parts are now exposed above the lowlands.

Following the formation of the valley there came a subsidence of the area, permitting the waters of the Gulf to extend northward to a point a short distance beyond the present junction of Ohio and Mississippi rivers. This extension of the Gulf took place in late Cretaceous times. During this time material was carried by the streams from the surrounding land areas and spread out over the bottom of the Gulf. The deposits formed at this time are of late Cretaceous age, and now lie buried beneath the younger ones to be considered later.

The character of the Cretaceous deposits within the area herein considered can not be definitely stated, but they probably consist largely of sand, clay, and marl, such being their nature farther south in the Embayment Area.

TERTIARY CONDITIONS.

Following the deposition of the Cretaceous strata, there came an increased subsidence of the area,[b] and as a result the borders of the Gulf were somewhat extended landward beyond those of late Cretaceous time. During this time material continued to be washed in large quantities from the land thereabouts and spread out over the Cretaceous deposits, resting against the edges of the old rocks around the border. This was during early Tertiary time, and the material deposited is of Tertiary age. As the region stood at a lower level during early Tertiary time than during late Cretaceous time, the Tertiary deposits therein lap farther over on the Paleozoic rocks than do the underlying Cretaceous.

POST-TERTIARY CONDITIONS.

The period of embayment, and consequently of deposition, was brought to a close by the elevation of the region, causing the Gulf to retreat southward and Mississippi and Ohio rivers to extend themselves over the newly formed Tertiary deposits.

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[a] Branner, J. C., Am. Jour. Sci., vol. 4, 1897, pp. 357–371.
[b] Harris, G. D., Geol. of Louisiana, 1902, p. 7.

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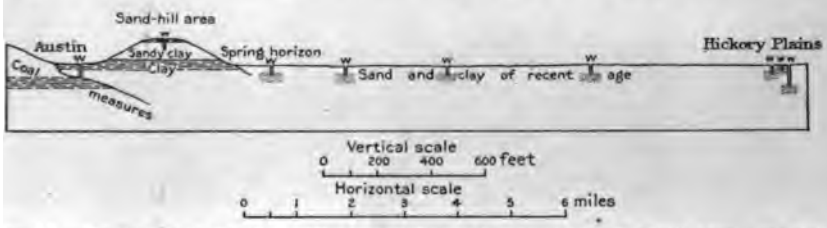
EROSION.

Crowleys Ridge.—At this time the Mississippi flowed to the west of hat is now Crowleys Ridge and the Ohio to the east of that area. ach of these streams wore away the Tertiary deposits to considerable epths, cutting out a wide valley and leaving Crowleys Ridge[a] as a emnant of the bed which, before the erosion took place, extended west-ard to the Arkansas highlands and eastward to those of Kentucky nd Tennessee. According to Professor Branner, the height of Crow-ys Ridge in Arkansas is "about 350 feet above the present tide level, 20 feet above the lowlands to the east and west." According to Pro-essor Marbut, as indicated by the topographic map accompanying his aper, it reaches in Missouri the height of 600 feet, or 280 feet above he lowlands.

The thickness of 120 feet in Arkansas and 280 feet in Missouri oes not indicate the total amount of erosion, for while the valleys to he east and the west of the ridge were being formed the top of the idge itself was suffering erosion. Just how much of it was removed



IG. 16.—Section from Austin to Hickory Plains, Ark., across the Sandhill area. *w*, Well.

s not known. Furthermore the valleys on either side of Crowleys idge were once deeper than now, having been partly refilled by iver deposits; so that a large part—indeed, most—of the material at nd near the surface of the lowland area is of Recent age. The total mount of erosion would be measured by the vertical distance between he base of the Recent deposits and the original surface of the ertiary.

Sandhill area.—As above stated, Crowleys Ridge is a remnant f the formerly widespread Tertiary rocks. The ridge mentioned nder the head "Topography of the lowlands," extending southward rom the town of Austin, is locally known as the Sandhill, a name dopted here for want of a better. This ridge also is an erosion emnant of Tertiary rocks, similar to Crowleys Ridge. As the name mplies, the soil is sandy. The other small hill east of Jacksonville s of the same origin and character as this, having been cut off from it

[a] For the history of Crowleys Ridge see Branner, J. C., Geol. Survey Arkansas, 1889, ol. 2, preface, pp. xiii, xiv; also Marbut, C. F., The evolution of the northern part of the owlands of southwestern Missouri: Univ. of Mo. Studies, vol. 1, No. 2, 1902.

by Bayou Two Prairie. With the exception of a bed of thinly laminated sandstone near the top of the ridge, rarely exceeding a foot in thickness, the material of these elevations is unindurated. It is, however, of an open, clayey nature, and has the power of standing unsupported in vertical walls for years.

Grandglaise area.—Another erosion remnant of Tertiary rocks lying along the western border, extending from Coffeyville southward to Bradford, is herein designated the Grandglaise area. The rocks of this area consist of indurated material, varying in character from a rather sandy limestone to one of comparative purity, most of it being quite fossiliferous. The beds lie in a horizontal position against the old Paleozoic rocks and occupy the narrow strip between the Iron Mountain Railway and the highlands.

Their greatest height is about 100 feet above the lowlands to the east. This limestone is mentioned by Dr. G. D. Harris,[a] and is classified by him as belonging to the Midway or lower stage of the Eocene Tertiary.

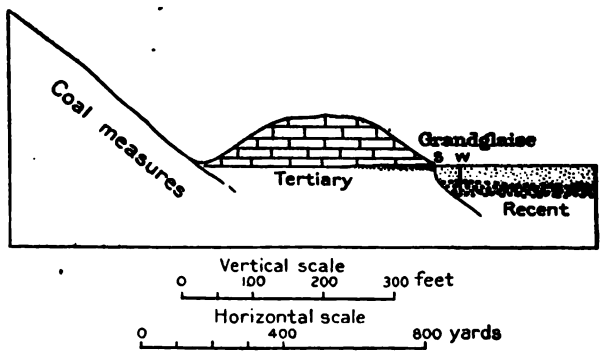


FIG. 17.—Section at Grandglaise, Ark. *w*, Well; *s*, spring.

DEPOSITS.

Sand and clay.—The lowland area, aside from the erosion remnants mentioned above, is covered with Recent river deposits consisting of sand and clay. Much the greater part is sand. Where clay is reported it is usually near the surface. In places there are as many as three thin beds within 40 feet of the surface. These beds are of uncertain extent, apparently occurring as lenses in the sand.

The number of deep-well sections is so limited as to make it impossible to ascertain the thickness of the Recent deposits over much of the area; but they of course vary with the topography of the old valleys before the filling began. On the supposition, yet remaining to be confirmed, that the gravel mentioned later in this paper as occur-

[a] Geol. Survey Arkansas, 1892, vol. 2, p. 24.

ring in the wells at Walnut Ridge, Hoxie, and Alicia represents the lower limit of the Recent deposits, these deposits are about 50 feet thick at the first two places and about 60 feet thick at the third. The assumption that this gravel represents approximately the base of the Recent deposits is supported by the section at Augusta, in which there is reported 100 feet of sand and clay resting upon a thin bed of clay, which in turn rests upon a bed of gypsum. (Fig. 18.)

There can be no doubt but that in this case the 100 feet of sand and clay are of Recent age. The thickness of the Recent deposits is shown

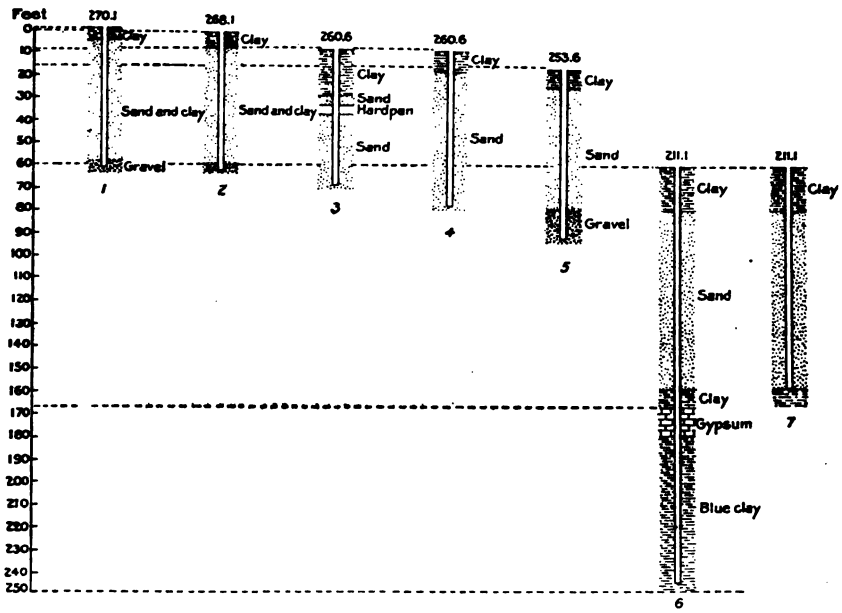


FIG. 18.—Well sections. 1, Well of Trumbull Wagon Co., Walnut Ridge; 2, well of the Iron Mountain Railway Co., Hoxie; 3, well of the Southern Cooperage Co., Minturn; 4, well of A. W. Shirrey, Minturn; 5, well of Iron Mountain Railway Co., Alicia; 6 and 7, wells of Campbell & Vinson, Augusta. Figures at top show the surface elevations of the near-by railway stations.

also in the section of the deep well at Newport, described later, where 105 feet of sand and clay, mainly sand, are reported as resting on "soapstone." The sand and clay in this case are of Recent age.

Gravels.—All along the Paleozoic border and lying upon the slopes of the escarpment above the Tertiary there are deposits of gravel and cobblestones of all sizes up to 6 inches or more in diameter. They are well rounded and have been derived largely, if not entirely, from the Paleozoic area adjacent to the Tertiary. In places they are cemented into conglomerate. The altitude of their upper limit is about 500 feet above sea level, or from 250 to 275 feet above the present level of the lowland area. As to whether these gravels are of Tertiary age or be-

long to the deposits known as "Orange Sand," "La Fayette formation," or any of the terms employed to designate similar deposits within the Embayment Area, the writer is not prepared to say. But the large quantity and size of the cobblestones, the fact that so great a percentage of them has been derived from the Paleozoic rocks on which they rest, and their general distribution along the Paleozoic escarpment argue against a fluviatile and for a marine origin of them. Whatever may have been their origin, it is certain that these gravels have suffered great change since their original deposition in all places where streams could get hold of them. Fine examples of this may be seen along the streams that are crossed in driving from Sulphur Rock to Newark. The large deposit of gravel on which Newark stands is probably of this worked-over material.

ROCKS.

TERTIARY.

The recent deposits of the lowland area rest upon deposits of the Tertiary period, this being represented by the Eocene rocks, the lowest and oldest of its series. The lowest division of the Eocene is the Midway, with which Doctor Harris has classified the limestone at and about Grandglaise.[a] By referring to the section, fig. 17, p. 94, it will be seen that this limestone lies in a horizontal position, and at a higher level than the Recent deposits to the east. That it does not represent the base of the Tertiary is shown by the occurrence of lignitic beds at Newport, about 11 miles distant, beneath which no limestone has been reported.

CRETACEOUS.

The most northern point within the area from which Cretaceous rocks have been reported is at Beebe, where Doctor Harris notes fossils of this age, taken from beneath the Tertiary in a well.[b] But that Cretaceous rocks extend over the whole of the area appears certain from our present knowledge of its history, according to which there was a subsidence at the close of the Cretaceous,[c] permitting the deposits of that age to be covered by those of Tertiary age.

In the absence of fossils from the deep wells of the region, and because of the similarity of the lower part of the Tertiary and the upper part of the Cretaceous, we are unable to determine the thickness of the latter. One mile southwest of Newport, in sec. 10, T. 11 N., R. 3 W., there is a drilled well, 1,000 feet deep, the deepest in the area studied, in which the following section is reported:

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[a] Op. cit.

[b] Geol. of Arkansas, 1892, vol. 2, pp. 10–11, 184.

[c] Harris, G. D., op. cit.; also, Geol. of Louisiana, 1902, p. 7.

Section of well near Newport, Ark.

	Feet.
Clay and sand	30
Sand	75
"Soapstone"	50
Quicksand	500
Rock of different kinds, ending in flint	345

The 105 feet of clay and sand at the top are of Recent age; the rocks from the base of the quicksand downward are supposedly Paleozoic. The 550 feet between the Recent and the Paleozoic may all be Cretaceous, though it is possible that the upper 50 feet, reported as "soapstone," is Tertiary.

PALEOZOIC.

The great mass of the substrata consists of Paleozoic rocks, in age passing from the Ordovician in the northern part to the upper Carboniferous in the southern part. The younger rocks lie unconformably upon these, resting against their truncated edges around the borders. (Figs. 16, 17, 21, 23, and 25.)

The Ordovician are the underlying rocks from the northern part of the area to about the latitude of Newport. South of there these rocks pass under those of Carboniferous age. (See fig. 8.) The kinds of rocks constituting the Ordovician, which would be penetrated in deep-well drilling north of Newport, after having gone through the unconsolidated Tertiary and Cretaceous beds, can be ascertained by referring to fig. 19. South of Newport shales, sandstones, limestones, and chert beds of Carboniferous age would be penetrated before reaching the rocks shown in fig. 19. The thickness of the Carboniferous rocks above the Ordovician would increase with the distance south from Newport.

GEOLOGY OF THE HIGHLANDS.

ROCKS.

As the rocks of the highland area lie in a practically horizontal position and the formations are of wide extent, the geology of the border can not well be discussed without at the same time including that of the entire highland area of the northern part of the State. The rocks of this area have long been known to be of Paleozoic age, the divisions represented being the Ordovician, Silurian, Devonian, and Carboniferous.

ORDOVICIAN.

The Ordovician rocks, which constitute most of the exposures north of White River within the area considered in this paper, consist mainly of magnesian limestone, though there are several beds of sandstone and some chert among them. Their lower limit is un-

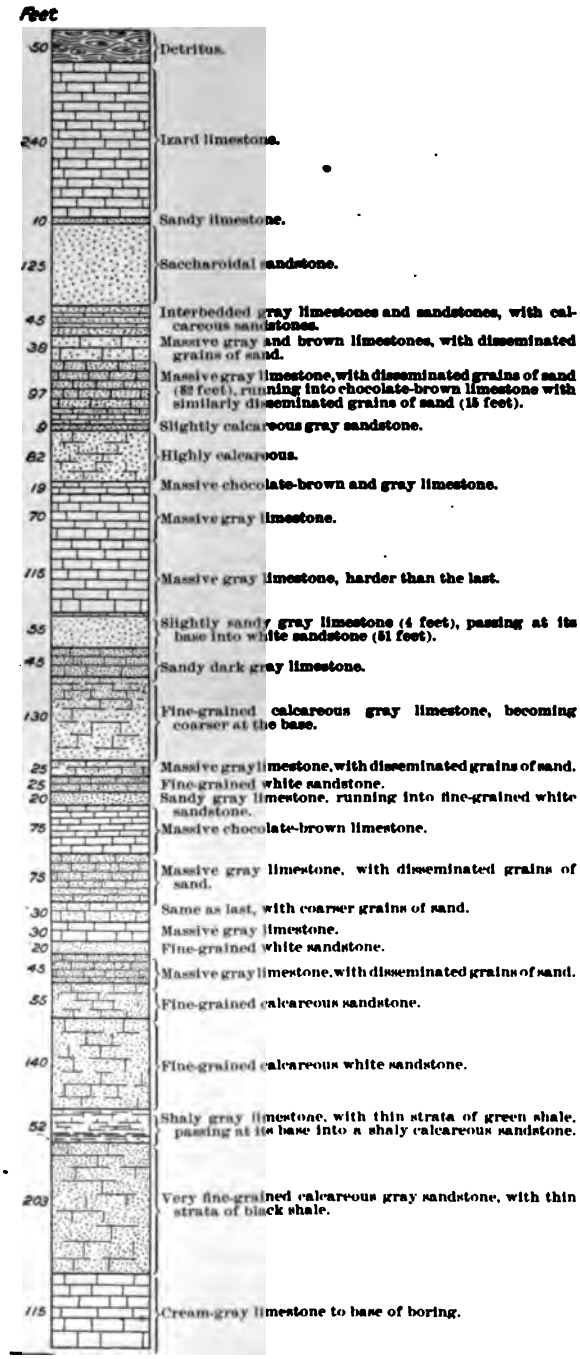

FIG. 19.—Section of deep well at Cushman, Ark.

known, but that it is very deep is disclosed by the section of a well at Cushman, heretofore published by the Geological Survey of Arkansas.[a] This well passes through 2,040 feet of Ordovician rocks without reaching their lower limit. As this section represents the most complete knowledge of the stratigraphy available, it is reproduced here.

SILURIAN.

St. Clair formation.—The Silurian is represented by the St. Clair formation. This is usually of a pinkish-gray color, and is generally highly crystalline. Where exposed it commonly shows in heavy layers which, as Doctor Hopkins observes, have probably been brought out by weathering, but sometimes it is massive. Its maximum thickness, as reported by Dr. T. C. Hopkins,[b] is 155 feet at Penters Bluff on White River. This

[a] Ann. Rept. Geol. Survey Arkansas, 1890, vol. 1, p. 118.
[b] Ann. Rept. Geol. Survey Arkansas, 1890, vol. 4, p. 214.

formation extends far to the westward from the longitude of Moorefield, but does not occur on the eastern border of the Paleozoic area.

DEVONIAN.

Sandstone lentil of Sylamore formation.—The sandstone lentil of the Sylamore formation, where observed by the present writer, varies greatly in character from a coarse-grained, saccharoidal sandstone, through a black, nodular, conglomerate-like rock, to black shale. When saccharoidal it is specked here and there by particles of limonite, which have resulted from the alteration of iron pyrite. Its thickness varies greatly within short distances, and in places it is entirely wanting. This formation is thought by Dr. H. S. Williams to belong to "the very close of the Devonian and the beginning of the Carboniferous."[a]

CARBONIFEROUS.

The rocks that belong to the Carboniferous and that enter into the hydrology of the eastern Paleozoic border are as follows, beginning with the lowermost: St. Joe limestone member of the Boone formation, Boone chert, Moorefield shale, Batesville sandstone, Fayetteville formation, Pitkin (Archimedes) limestone, Morrow formation (Boston group), and Coal Measures, or Pennsylvanian.

The first four of these belong to the Mississippian series. The position of the Pitkin limestone is yet doubtful, but the probability is that it also belongs to the Mississippian. The Boston group and the Coal Measures, which are mapped together, consist of 400 feet of sandstone and shale, containing at least one and probably two beds of limestone.

St. Joe limestone member, Boone formation.—The lowest member of the Carboniferous is the St. Joe marble, a more or less crystalline limestone, varying in color from gray to red, usually thin bedded, and from 25 to 50 feet thick. This formation has not been observed along the eastern border of the Paleozoic area.

Boone chert.—The Boone chert, which lies above the St. Joe member, is over 300 feet in thickness. It is essentially a bed of limestone, in places quite crystalline, containing a large amount of chert in lenses parallel with the bedding. The relative amounts of calcareous material and chert vary greatly, both horizontally and vertically. In places the formation is chiefly limestone, while in others the chert constitutes practically the entire mass. So abundant is the chert in all places where this formation is exposed that a large amount of detrital material occurs on the surface as a residual product left from the solution by underground water of the calcareous material with which it is associated. The calcareous beds are

[a] Ann. Rept. Geol. Survey Arkansas, 1892, vol. 5, p. 319.

penetrated by numerous joints, which in many places have been enlarged by solution into caverns, and the cherty portions are always profoundly fractured.

Moorefield shale.—Resting upon the Boone formation in the eastern part of the Paleozoic area is a bed of shale somewhat more than 100 feet thick. This formation is wedge-shaped, thinning out westward, and is wanting in the central and western parts of the State. It was mapped in the reports of the Arkansas Geological Survey as Fayetteville shale on the belief that it was in the same stratigraphic position occupied by that formation in the western part of the State, where it is typically represented. But while it closely resembles the Fayetteville shale it differs from it in that the laminæ are thicker, in having greater resistance to atmospheric action, and in being of a duller dark color. Hence the new name Moorefield shale has been adopted, it being typically developed at the town of Moorefield.

Batesville sandstone.—Above the Moorefield shale is the Batesville sandstone, which, on the south side of White River at Batesville, has a thickness of something more than 100 feet. It lies in beds which vary from a few inches to 3 or 4 feet in thickness, is of a brown color, and of considerable porosity. Quarries in this stone furnish beautiful slabs of almost any thickness and size desired. This formation gradually thins to the western part of the State, where it is usually only a few feet thick and in many places is entirely absent. This is the same sandstone that is known as the Wyman sandstone in the reports of the Arkansas Geological Survey.[a] As the Moorefield shale is absent in the central and western parts of the State, the Batesville sandstone, when present there, rests directly upon Boone chert. When the Batesville sandstone is absent the Fayetteville shale rests upon the Boone chert.

Fayetteville formation.—The Fayetteville shale is of wide extent, reaching from the eastern border of the Paleozoic area westward, far beyond the borders of the State. It is seldom less than 25 extent, reaching from the eastern border of the Paleozoic area westward, far beyond the borders of the State. It is seldom less than 25 feet thick and in many places exceeds 100 feet, especially along the eastern border of the Paleozoic area. It is of a lively dark color, very thinly laminated, easily broken down under atmospheric influences, is intersected by numerous clean-cut joints, and contains a great many concretions of large size. Though of wide east-west extent, it is of uniform nature throughout. Indeed, the uniform lithologic character of the different formations constituting the Paleozoic rocks of northern Arkansas is one of the features of the geology that most strongly impress themselves upon the observer in the field.

Pitkin (Archimedes) limestone.—The Pitkin limestone, which in the eastern and central parts of the Paleozoic area rests upon the

[a] 1888, vol. 4, pp. 38–41.

Fayetteville shale, is usually from 10 to 20 feet thick. But in the eastern part of the region, between Salado Creek and Goodey Creek, it is 100 feet thick. As a rule, it is composed practically entirely of calcareous matter, but in places contains enough siliceous matter to give it the appearance of the Boone chert.

As above stated, there is, in the eastern part of the Paleozoic area above the Pitkin limestone, about 400 feet of sandstone and shale, including a small amount of limestone. This is mapped together as the Boston formation and the Coal Measures.

FIG. 20.—North-south section through Batesville, Ark., showing the structure and formations of the Paleozoic area.

STRUCTURE OF THE HIGHLANDS.

The structure of the northern part of the region is on the whole quite simple, the beds dipping southward at a low angle, this dip being disturbed locally by faults of greater or less throw, and by small flexures. In the flexuring some of the more brittle rock, especially of the Ordovician area, suffered a great deal of fracturing, producing brecciated belts of greater or less width. The accompanying section through Batesville to the summit of the Boston Mountains (fig. 20) gives a general idea of the structure and stratigraphy of the region. That portion of the section south of Batesville represents the structure and stratigraphy as determined by the writer. That north is adapted from a section by Dr. R. A. F. Penrose, jr.[a]

South of the Boston Mountains, near the latitude of the town of Beebe, the usual south dip of the rocks is succeeded by east-west anticlinal and synclinal folds. These folds are the result of the northward-diminishing tangential force which, south of Arkansas River, is expressed in the Ouachita Mountains.

PALEOZOIC-TERTIARY CONTACT.

PALEOZOIC ESCARPMENT.

The Paleozoic escarpment along the line of the Paleozoic-Tertiary contact has already been alluded to under the head of "Topography of the highlands." This escarpment is of such

[a] Geol. Survey Arkansas, 1890, vol. 1, pocket map.

nature as to make it certain that during Tertiary time, when the waters of the Gulf of Mexico covered all of what is now the lowland area of the State, the plateau portion of the Paleozoic area terminated along the seashore in bold, high cliffs, while the east-west ridges of the region to the south projected into the sea as capes.

Fig. 21 shows the general relations of the rocks of the two different ages. It will be noticed by an inspection of this figure that the

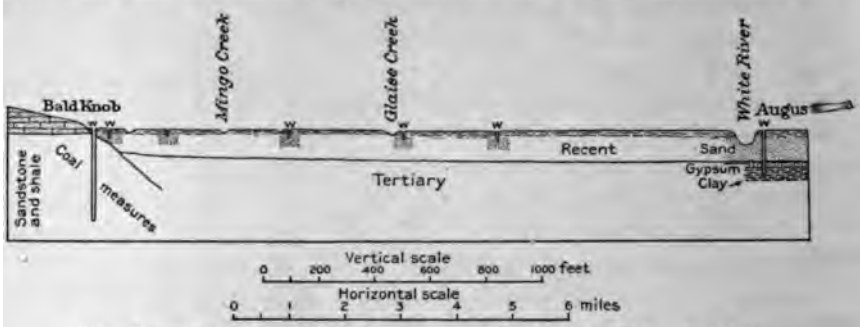

FIG. 21.—Section from Bald Knob eastward to Augusta, Ark. w. Well.

Paleozoic rocks pass at a high angle beneath those of later age. The same thing is shown by the section at Newark (fig. 25, p. 109), and many other similar sections might be produced.

OSCILLATIONS DURING TERTIARY TIME.

The above-mentioned sections, together with the steep nature of the Paleozoic escarpment in many places, indicate that the shore line

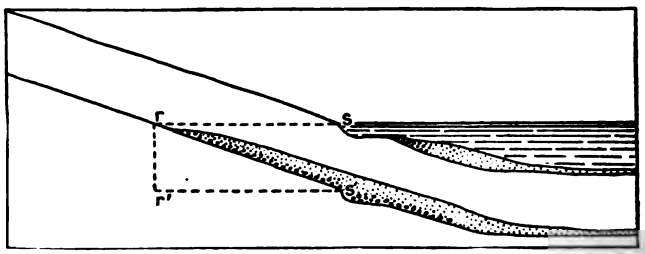

FIG. 22.—Diagram showing encroachment of the sea upon the land as a result of land subsidence. *s*, Position of the shore line before subsidence; *r*, position after subsidence; *rr'*, amount of subsidence; *sr*, the transgression of the sea upon the land as a result of the subsidence.

must have remained at about the present level of the lowlands for some time—long enough for the wave action to have worn away the Paleozoic rocks to their present form. On the other hand, the slope of the part of the Paleozoic escarpment above the line of contact, over which the plateau gravel is distributed, is so gradual as to permit wagon roads over it. At some time during the Tertiary period

the Paleozoic region must have subsided to a point at least 500 fe lower than its present height, that being the height above sea lev of the upper limit of the gravel. This will be understood by an inspection of fig. 22. If the shore line remains stationary for some time a terrace will be produced, as is shown at s; but if, after subsidence begins, it continues as a gradual movement, bringing about a constant shifting of the shore line landward, then at most but faint terracing will take place. The writer observed no terraces over the region of the plateau gravel, though it would not be surprising if more careful search should lead to their discovery. At any rate, the topography of the plateau gravel indicates that there was a gradual transgression of the Tertiary sea westward from about the present margin of the lowlands until the region sank 500 feet below its present level, after which it was reelevated. It is altogether reasonable to assume that at least a part if not all of the gravel was formed at the time of the upward impulse as a result of the rejuvenation of the streams.

FIG. 23.—Generalized north-south section showing relations of Paleozoic and later formations.

STRUCTURAL RELATIONS OF THE PALEOZOIC AND LATER FORMATIONS.

The stratigraphic relations of the Paleozoic and younger formations may be seen by an inspection of figs. 21, 22, 23, and 25. The origin of these relations will be understood when it is recalled that the older rocks formerly extended eastward and joined onto the same rocks in the highlands beyond Mississippi River and were worn away by streams and wave action until their truncated edges occupied their present position, after which the younger formations were laid down upon them, abutting against their truncated edges. It will be noticed that in an east-west section the rocks of both ages are practically horizontal. It has already been stated that the general dip of the Paleozoic rocks is southward. This and the fact that the line of contact between the Pale

zoic and the younger rocks is northeast-southwest brings the older rocks under the younger along the north-south line, as shown in fig. 23.

UNDERGROUND WATER RESOURCES.

GENERAL STATEMENT.

By underground water, or ground water, is meant the water in the rocks of the earth, whether those rocks consist of indurated or loose material. The source of all water of the land is the ocean, from which it is carried by the winds in the form of vapor and precipitated from the atmosphere as rain, snow, hail, and sleet. Falling upon the earth, a part of this water, which collectively is known as meteoric water, enters the ground, and in so doing becomes ground water. Another part flows off over the surface and is known as run-off. Whether a particle of water becomes ground water or run-off, it in either case at once seeks its way back toward the ocean. This is as true of the ground water as of the run-off, though the usual velocity of the former is much less than that of the latter. Indeed at times it may be nil.

The relative amounts of run-off and ground water depend upon a great many things, among which are the slope, the character of the surface material, the presence or absence of vegetation, and the time distribution of the rainfall.

A steep slope is conducive to a large run-off and a small amount of ground water; a flat slope, to a small run-off and a large amount of ground water. A thin soil is conducive to a large run-off and small amount of ground water; a thick soil, to a small run-off and large amount of ground water. Absence of vegetation is conducive to a large run-off and a small amount of ground water; the presence of vegetation, to a small run-off and a large amount of ground water. Compact rocks are conducive to a large run-off and a small amount of ground water; porous ones, to a small run-off and a large amount of ground water. Torrential rainfalls are conducive to a large run-off and a small amount of ground water; slow rains, to a small run-off and a large amount of ground water.

Favorable conditions for the occurrence of ground water are those in which porous rocks, as sandstone, are exposed at the surface and are underlain by close-textured rocks, as shale. An area of porous rocks so exposed is known as a catchment or collecting area.

The upper limit of saturation of the rocks is known as the water table; otherwise as the ground-water level, or the ground-water surface. All the rocks beneath the surface within a limited area may contain all the water they are capable of holding: the water table is

then either at the ground surface or above it, in the latter case producing ponds. Or there may be a zone of rock in which there is but little water, this zone being bounded by the ground surface above and the water surface below; such a zone varies in thickness in different localities and in the same locality with the wet and dry seasons. Wells sunk into the ground below the water table fill up to it. Streams that have cut their valleys below the water table drain off the ground water, which issues as seeps and springs.

In a region like the lowland area of Arkansas, where the surface is level and the material constituting the sediments is loose and sandy, the water table is well defined and is practically parallel with the surface. But in a hilly region of consolidated rocks it is usually poorly defined and conforms to the surface only in a general way. Usually it is farther from the surface on the hills than in the valleys; so that, as a rule, wells on hills are of necessity deeper than those in adjacent valleys.

The amount of water that a formation contains depends upon a great many things, among which are its thickness, porosity, relation to other beds, and the amount and time distribution of the rainfall. It goes without saying that if all else is equal a thick formation is a better source of water than a thin one; also that a porous formation is a better water producer than a less porous one. Sandstones and pudding stones contain a great deal of water under favorable conditions; loose sand and gravel contain more; shale and clay, being close textured, neither hold much nor permit the passage of much through them.

Limestones are usually compact in hand specimens, but in the beds they are jointed, the joints frequently having been greatly enlarged by the solvent power of the water that finds its way through them. So that a formation of limestone resting upon a bed of shale is almost certain to be, as in the case of sandstone similarly situated, an important water producer.

UNDERGROUND WATER OF THE HIGHLANDS.

As already stated, the rocks of the Paleozoic area consist of a great thickness of Ordovician limestone, upon which is superimposed, in the eastern part of the area, sandstones, shales, and limestones aggregating 1,100 feet or more in thickness. Among these rocks along the eastern border there are four important water horizons.

ORDOVICIAN.

The lowest of these in the geologic column is in the great deposit of Ordovician limestone which is spread over a considerable area in

the northern part of the State. As the topography of this region is somewhat old, the former steep slopes having been worn off into more or less rounded ones, and as the rocks themselves are considerably fractured along lines of folding, permitting the water to enter, the conditions are such as to result in a considerable supply of ground water.

This water issues as springs along those courses where denudation has brought the stream valleys below the ground-water level. Wells are not uncommon, but, as the water table is frequently some distance from the surface on the divides between the streams, cisterns are frequently resorted to for water supply. An additional reason, however, for the use of cisterns is found in the fact that the water of this region, moving as it does almost entirely through limestone, is very hard.

The most common method of sinking wells in this horizon is by digging and blasting, but drilling is sometimes resorted to. It will be remembered that in the quest of water in limestone, success depends upon striking a water-producing fissure, the stone being so compact as to prohibit water from moving through it except along lines of fracture. In so far as the chances of striking a fissure are increased by increase of well diameter, blasting is the most promising method; but, on the other hand, the chances of striking a fissure are greater in a deep well than in a shallow one, and as the cost of drilling is much less than that of blasting, the former method is advisable in most cases. Especially is this true when the sanitary advantages of a carefully cased drilled well over an open one are taken into consideration.

CARBONIFEROUS.

Boone formation.—The next water-bearing stratum of importance in the eastern part of the Paleozoic area is in the Boone formation. The great thickness of this, together with the much-fractured character of its chert and the jointed structure of its limestone, combine to make it the most important water-bearing formation in the Paleozoic region of northern Arkansas. Where this is the surface rock the limestone of the upper part has been removed by solution, but the insoluble chert is left as a residue upon the surface, in many places several inches thick. In such places this chert débris largely reduces the run-off and by so much adds to the ground water. The large number of joints in the limestone permit the water to descend, and the fractured nature of the chert lenses allows it to be freely transmitted horizontally.

Along the courses of the streams which have cut their channels into this chert below the water table issue many strong, beautiful springs, and, except on the high divides, an abundance of water can

be secured from it by digging wells. As a large part of the formation is chert and practically insoluble, the water is not particularly hard.

Batesville sandstone.—The Batesville sandstone, lying between the Moorefield shale below and the Fayetteville formation above, is a water-bearing horizon of much importance. This formation at Batesville is about 100 feet thick. It is the surface rock over a considerable area, and being of a porous nature, collects a great deal of water which is retained because of the thick bed of impervious shale beneath. Within the area of the Batesville sandstone that formation furnishes practically all the water that is used. It was the source of the water supply at the city of Batesville before the water plant was installed there. Wells sunk almost anywhere in this rock furnish water, and springs emerge from it along the stream valleys. The water is soft and well adapted to domestic uses.

Pitkin (Archimedes) limestone.—The next water-producing stratum of importance is the Pitkin limestone. This formation lies at the top of the Fayetteville shale (fig. 20) and beneath several hundred feet of sandstone and shale. It is considerably jointed, and this fact together with its stratigraphic position makes it an important spring horizon. Its jointed nature permits it to receive the water that comes from above, which the impervious Fayetteville formation prevents from escaping below, so that springs are common at the base of this formation on the hillsides where it outcrops. As might be expected, the water is hard.

Morrow formation (Boston group) and Coal Measures.—Along the eastern border of the Paleozoic area there are 400 feet of sandstone and shale, with some limestone, above the Pitkin limestone. In this there are several water horizons of minor importance. Near the top of the Boston Mountains the sandstone becomes coarse grained, even approaching a conglomerate. This coarse character of the rock makes it a good water producer, and wells are common even on the highest parts.

UNDERGROUND WATER OF THE LOWLANDS.

ORIGIN OF THE WATER.

The ground water of the Arkansas lowlands has three sources: (1) That which sinks directly into the ground from the rainfall; (2) that which leaks from the streams flowing from the Paleozoic region; (3) that which leaks from the truncated edges of the Paleozoic rocks.

Rainfall.—Though no data is at hand by which the amount supplied from each of these sources can be approximated, there is hardly a doubt but that the principal source is the first one mentioned. The

average annual rainfall, according to the records kept by the United States Weather Bureau at Newport, extending over several years, is about 48 inches. The extremely level surface, the open, sandy nature of the soil, and the large amount of sand in the recent deposits are all conducive to a small run-off and a large amount of ground water. While a large portion of the surface of the lowlands is of a clayey nature, it is sufficiently porous to permit the water to pass through it into the sandy beds below. That portion of the area from Newport northward and extending westward to Black River is very sandy. There is also a great deal of sand between Newport and Augusta east of White River. This surface sand serves as a collecting reservoir in which the rain water is held while it slowly sinks into the strata beneath.

Stream leakage.—The amount that is supplied by stream leakage, while problematical, is doubtless large. It is a matter of common observation by those who live near the principal streams that the wells rise and fall with the fluctuations of the streams. If the statements of the people can be relied upon, wells situated several miles from Black River and White River are thus affected. The

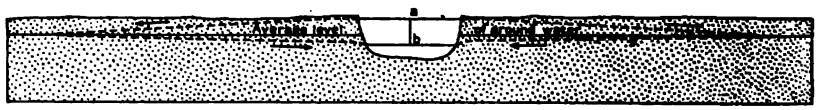

FIG. 24.—Diagram showing the infiltration of water from a stream into adjacent sandy beds.

reasons for this will be made apparent by reference to fig. 24. The unconsolidated and usually sandy nature of the material permits the free movement of the water either toward or away from the river, according to the slope of the water table. While the river is at the height *a*, and above the general level of the ground water, the movement will be from the river outward. During such times an enormous amount of water is contributed by streams to the region on either side. When the level of the stream is at *b*, below the general level of the ground water, the movement is toward the stream, which is then changed from a source of supply to a line of drainage; but as the surfaces of the main streams are seldom more than 20 feet below the country on either side, the zone which they can at any time drain is limited to a depth of only a few feet from the surface, represented by the line *ab*.

Leakage from the Paleozoic rocks.—The amount of water supplied by this source, while probably smaller than that from either of the others, must be considerable. The edges of the Paleozoic rocks are truncated to a considerable depth, and the loose deposits abut against the truncated edges. (See figs. 16, 17, 21, 23, and 25.) With this in mind, also remembering that the Tertiary-Paleozoic line of

contact has a northeast-southwest course, and that the Paleozoic rocks dip south, it will be seen that the leakage from the old into the young rocks must be very great.

WATER HORIZONS.

There are but three areas within the region, all of limited extent, where well-defined water horizons have been made out above the Paleozoic rocks. These will be designated as the Newark, Grandglaise, and Sandhill horizons.

OCCURRENCE.

Newark horizon.—Attention has already been called to the gravel at Newark as a source of water. The considerable amount of this gravel, its unconsolidated nature, its stratigraphic situation on the Moorefield shale, and its location on the border of the highlands from

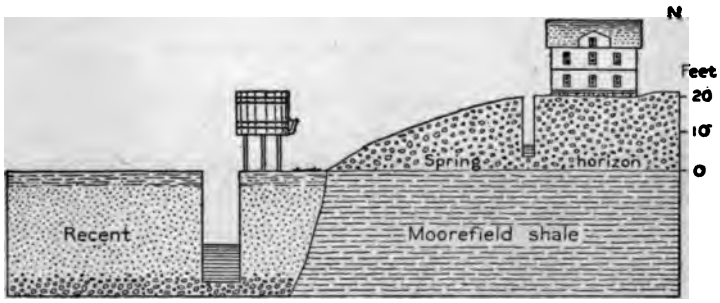

FIG. 25.—Section at Newark, Ark., showing relations of the Moorefield shale, the Newark gravel and the recent deposits; also the occurrence of water in the last two.

which it receives the drainage, all combine to make it an excellent water reservoir. Wells sunk into this gravel produce an abundance of excellent water. (Fig. 25.)

Grandglaise horizon.—The water horizon at Grandglaise, consisting of a bed of loose sand overlain by Tertiary limestone, has already had attention under the head of "Springs." It is probable that this sand is underlain by clay, though no exposure was observed where it could be seen.

Sandhill horizon.—In the Sandhill area there is a well-defined water horizon above the bed of clay which underlies the ridge. (Fig. 16.) This horizon is due to the sandy surface, which makes it a good collecting area, to the porous, sandy nature of the clay beneath the surface, and the impervious stratum below. It is from this horizon that the residents of the area obtain water. The sandy clay from which water is secured has the property of standing unsupported for many years. Wells that are said to have been dug before the civil war and left without walls, except a few feet next the surface, are still in an excellent state of preservation. Whether wells are dug or bored, they always furnish a copious supply of water.

Other horizons.—The gravel bed in which the wells at the Trumbull Wagon Company's plant at Walnut Ridge and that which supplies water for the Iron Mountain Railway tank at Hoxie are sunk probably represents an important local horizon from which it would be advisable to seek water. These wells are 60 and 62 feet deep, respectively. It would not be a difficult matter to drive wells into this gravel which would furnish an abundance of water for family, hotel, or stock purposes.

Unfortunately the number of deep wells is not sufficient to determine the extent of this gravel bed. The well which supplies the railroad tank at Alicia is said to be 75 feet deep and to extend into gravel for 14 feet. This is probably the same gravel that occurs at Walnut Ridge and Hoxie. At Newport there are two bored wells, belonging to the Newport Ice and Cold Storage Company, 97 and 102 feet deep, respectively, but from neither of these is gravel reported.

LACK OF DEFINITION OF HORIZONS.

Aside from the above-mentioned water horizons, none of more than local importance were determined. The whole ground is thoroughly saturated with water from within a few feet of the surface downward. Most of the material within 100 feet of the surface is sand, which allows the water to move freely through it when the conditions for movement are supplied. While this sand contains beds of clay, these are of local extent and occur at different levels, so that there is nothing to prevent the free commingling of all parts of the ground water, especially where a portion of the water from a considerable distance below the surface is removed, as is the case in pumping from deep wells. The removal of water in considerable amounts from wells causes a more or less rapid flow from above and about the point of removal. The deeper the well the greater the area drained and the more water involved in the movement. For these reasons no distinct horizon of any considerable extent from which the water is materially different from that above or below is to be expected.

The reason for want of definition of water horizons within the area will be better understood when the manner of deposition of most of the material in which wells are sunk is recalled. This is of Recent age (fig. 21, p. 102) and is stream deposit. It was built up by the overflow of streams and the consequent deposition. The difference that is found in the character of material beneath the surface at the same level is precisely like that in the surface of flood plains—sand here and clay there. As the streams shifted, now to one side and now to the other, the character of the material at all points changed, so that beds of sand and clay have come to alternate.

The great variation in the character of the deposits within short distances may be seen from figs. 26 and 27, which show sections at Tupelo and at Weldon and Auvergne.

CHEMICAL CHARACTER OF THE WATER.

In the absence of analyses, it is possible to give only the general character of the water. The water over the lowland region is in nearly all cases reported as hard. Only the comparatively small number of wells that are in superficial sand deposits produce soft water. The residue from evaporation around the valves of boilers frequently contains a great deal of common salt. Some of the wells between Bald Knob and Augusta contain so much salt as to render the water unfit for drinking purposes. Most of the water forms a scum of hydroxide of iron on the surface after standing a few

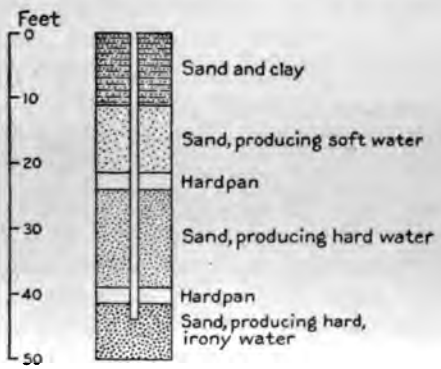

FIG. 26.—Section at Tupelo, Ark.

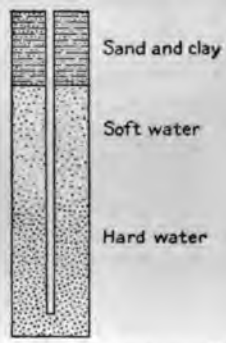

FIG. 27.—Representative section at Weldon and Auvergne, Ark.

hours, and a yellowish stain of the same material lines vessels in which water from almost any of the wells is used. The amount of organic matter contained in the water is great in many cases.

The character of the water varies greatly with depth. Also it often varies greatly in short horizontal distances. Frequently wells of a given depth furnish fairly good water, while those near by, either shallower or deeper or of the same depth, supply water which is unfit for use. The difference in the character of the water from different depths is explained by the vertical variation in the character of the beds. The difference in the character of water in wells which are close together and of the same depth is accounted for in the horizontal variation of the beds (fig. 28). It is a common thing for two wells to be situated near together, the water of one being good, while that of the other can scarcely be used on account of the large amount of iron and organic matter contained in it. This difference of the water within short distances is so well known to the

residents that often when bad water is secured the pipe is "pulled" and driven in another place near by.

This great difference in the character of the water within short distances results from the manner of deposition of the material. A detailed map of the region would show hundreds of sloughs, which are abandoned channels of streams. The water in these sloughs is stagnant, and the borders are lined with aquatic plants which annually die, adding their material to the mud of the bottom. Besides the plants, these sloughs all contain a large amount of driftwood and are favorable places for the accumulation of iron ore in greater or less amounts. Hundreds of such sloughs have become buried by the flooding of adjacent streams, there being nothing left on the surface to indicate their presence beneath. The organic matter in these buried sloughs, absent from the atmosphere, reduces the insoluble iron compounds to soluble forms, which, together with the organic acids from the decay of the vegetable matter, are taken up by the water;

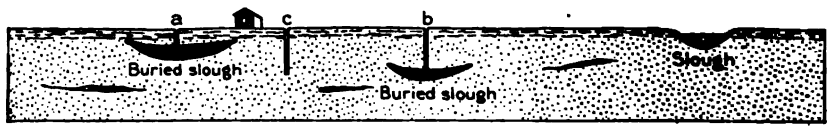

FIG. 28.—Diagram showing buried sloughs. Wells at *a* and *b* would furnish water containing iron and organic matter. The well at *c* would furnish comparatively pure water.

so that a well driven into one of these buried sloughs, as shown in fig. 28, would furnish water unfit for use, while another near by might furnish comparatively good water.

USES OF THE WATER.

The inhabitants of the region depend wholly upon the water that can be secured at their doors for domestic and stock purposes. The cities that have waterworks, such as Newport, Augusta, Argenta, and Jonesboro, get their water from wells. Batesville uses water from White River.

The lumber and other manufacturing industries of the region demand a large amount of water for boiler purposes. Unfortunately, all the water forms more or less scale in the boilers, and in some cases it is found advisable to resort to the use of boiler compounds to prevent this. The most troublesome scale is that formed from a combination of fine sediment and the calcium and magnesium precipitated from boiling.

At Lonoke experiments have been made in rice culture on a small scale, using water from wells for irrigation. Should the climatic and soil conditions be found favorable to this culture, no reason

exists why it should not become an important industry, for there is an abundance of water for irrigation.

SPRINGS.

The number of springs within the lowland area is so limited that for all practical purposes they might be left out of consideration as water producers. There are but three localities within the lowlands where springs occur, viz, at Newark, Grandglaise, and the Sandhill area east of the towns of Austin and Cabot. The limited number of springs is due to the usually level surface of the region, the horizontal position of the beds, and the shallow stream valleys. The springs at the localities mentioned issue from erosion remnants, the edges of whose horizontal beds outcrop above the adjacent areas.

As previously stated, the town of Newark is situated upon a heavy deposit of gravel, probably of post-Tertiary age. This gravel is an excellent source of water, as it rests directly upon the Moorefield shale, which, because of its impervious nature, prevents the water from sinking (fig. 25, p. 109). In the eastern part of the town, at the base of the gravel and the top of the shale, there are several springs.

At Grandglaise a spring of considerable strength issues from a bed of loose sand beneath the Tertiary limestone and just above the level of the lowlands to the east. There is another spring at the same horizon, about half a mile south of Grandglaise station.

East of the towns of Austin and Cabot are several springs which issue from the slopes of the ridges on the east, north, and west sides. Among these are the Camp Grounds Spring, NW. ¼ sec. 22; Crab Tree Spring, sec. 9; and some four or five springs in sec. 16—all of them in T. 4 N., R. 9 W. As will be seen from fig. 16 (p. 93), the Sandhill area is underlain by a bed of clay near the base, which, being impervious, causes the water to flow out on the hillsides as springs.

WELLS.

CHARACTER OF WELLS.

While but few springs occur within the region, there is no limit to the possible number of wells. The ease with which water can be secured from wells anywhere within the region causes them to be resorted to for water even in the few localities where springs occur.

The deepest wells that have been sunk in the region are in the neighborhood of 100 feet. However, there are but few places where water can not be secured within 20 feet of the surface. Usually where wells have been sunk to a greater depth than 30 or 40 feet, it has been with the reasonable assumption that the quality of water improves with depth and not because there was an insufficient supply near the surface.

However, the advantage of a well which terminates in gravel over one that stops in sand within a few feet of the gravel is in the fact that its open nature permits a free flow of water to take the place of that pumped out—a flow sufficient to supply the demands for any purpose—and in that all possibility of sand entering the pipe is precluded. There is no reason to believe that the quality of water obtained from the gravel is any better than that from the sand immediately above, with the exception that the former is free from sediment, for the two contain the same bed of water. Water, of course, from near the surface is less suitable for domestic purposes than water from greater depths, but the difference between the water from the gravel and that from a few feet away is certainly very little.

METHODS OF SINKING WELLS.

Formerly the only means of securing water was by digging open wells. While a good many dug wells are still in use, that means of seeking water has been succeeded by driving and boring. Driving ordinarily necessitates but a few feet of iron pipe, a driving point, a pump, and a few hours' work. The pipe is sometimes of common iron, sometimes galvanized, and is usually 1¼ inches in diameter.

FIG. 29.—Style of drive-well point commonly used.

The point is made of perforated gas pipe, covered with brass wire cloth, usually 60, 80, or 100 mesh, and protected by a perforated brass jacket. The pump is usually of the style known as the "pitcher pump."

Bored wells are in most cases 8 inches in diameter, the water being raised by a windlass and cylinder bucket with a valve at the bottom.

A few windmills are in use, but water for domestic purposes is commonly raised by hand.

Whether boring or driving is resorted to seems to be a matter of local custom. In the southern part of the region, between Hickory Plains and West Point, nearly all the wells observed by the writer are bored, though there is no apparent reason why they should not as well have been driven. In the northern half of the region a bored well is seldom seen, except in those cases where a large amount of water is desired and where the wells are of considerable depth. In all parts dug wells are occasionally met with, but since the advent of the iron pipe and "pitcher pump" the relative number of these is constantly decreasing.

An ingenious method of sinking deep wells is employed by Mr.

H. F. Close, of Bismarck, Mo. Into a piece of pipe of the desired size is fastened a triangular bit, as shown in fig. 30. A cap is screwed onto the upper end of the pipe, to which is attached a hose with swivel, permitting the pipe to be turned, auger-like, by a hand lever attached to the top, by which process the bit cuts down through the loose material. At the same time water is forced through the hose and down the inside of the pipe by a steam pump, thus moving the material loosened by the bit and carrying it upward around the outside of the pipe to the surface. By this method it is claimed a well can be sunk at the rate of 12 or 15 feet an hour.

CAPACITY OF WELLS.

The amount of water that can be supplied by almost any well within the lowland area is limited only by the capacity of the pipe. When a great amount of water is needed, either a large pipe is used or the number of wells is increased until the desired amount is

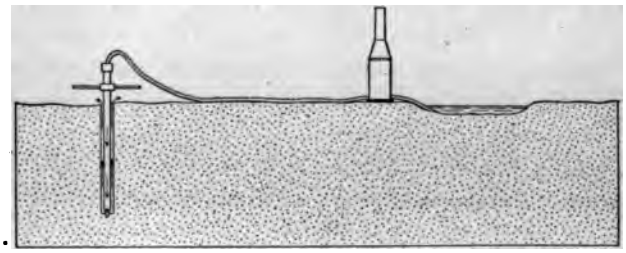

FIG. 30.—Diagram showing an ingenious method employed in sinking deep wells.

secured. An idea of the amount of water available within the region can be secured from the following table of so-called deep wells:

Deep wells in northern Arkansas.

Place.	Owner.	Depth.	Diameter.	Amount supplied per day.
		Feet.	*Inches.*	*Gallons.*
Walnut Ridge	Trumbull Wagon Co	61	6	104,000
Hoxie	Iron Mountain Rwy	62	10	45,000
Minturn	Southern Cooperage Co	60	1½	30,000
Alicia	Iron Mountain Rwy	75	6	[a] 9,000
Newport	Newport Ice and Cold Storage Co	97	6	40,000
Higginson	Iron Mountain Rwy	68	12	30,000
Augusta	Campbell & Vinson	100	6	50,000
Argenta	Buckeye Cotton Oil Co	75	6	([b])
Do	Rose City Cotton Oil Co	60	6	10,000

[a] Per hour. [b] Water supplies oil plant.

It is probable that the figures showing the amount consumed represent but a small part of the capacity of the well in each case, for it is invariably reported that the amount used lowers the water very little. The well supplying the railroad tank at Alicia has a capacity of 9,000 gallons an hour, and the pumper thinks this supply would be kept up even with constant pumping.

The great capacity of these wells is due to the loose and sandy nature of the material in which the water occurs, and the fact that it is saturated to within a few feet of the surface. As fast as the water is removed it is supplied, as the result of easy transmission through the sandy material and the downward pressure of the column of water between the lower limit of the well and the ground-water level. The supply is practically inexhaustible.

PROSPECTS FOR FLOWING WELLS.

The conditions for flowing wells are:

(1) A bed capable of holding and transmitting water. Such a bed is known as a reservoir. Its capacity for water may result from loose sand or gravel, porous consolidated rock, or fracturing. The capacity for water and the ease with which it moves increase with the open nature of the reservoir.

(2) A confining stratum above the porous bed to hold the water down and keep it from leaking out. It is necessary for the confining bed to be composed of close-textured rock, such as shale, clay, or other fine silts, through which the water can not readily pass.

(3) A head of water somewhere in the reservoir at a higher level than that of the surface where the well is desired. The minimum vertical distance that can exist between the water level of the head and the mouth of the well is determined by the distance they are apart and the porosity of the reservoir. The farther apart the greater the minimum difference of elevation between the two. This is due to the increase of friction with distance as the water moves through the reservoir. The more porous the reservoir the less will be the friction and consequently the less the minimum vertical difference that can exist between the two.

The very small difference in altitude between the highest and lowest parts of the lowland area preclude the possibility of securing artesian water from the Tertiary or Cretaceous rocks, even though all the other conditions were favorable. If flowing wells are sought within this region, it should be with an understanding that it is necessary to go through the Tertiary and Cretaceous into the Paleozoic rocks below.

While the securing of flowing wells from the Paleozoic rocks may not be outside the possibilities, the chances for doing so are slight. As has been noticed on preceding pages, these rocks contain excellent

water-bearing formations, and their south dip would bring them, if the beds were continuous, under the younger deposits, in which case the chances of securing artesian water from them should be excellent. But these beds are truncated to considerable depths, and from their truncated edges a large amount of water passes out into the younger rocks, this being one of the sources of the ground water of the lowlands. It follows that if flowing wells be secured from these rocks, it must be from below the level to which they are truncated.

A further fact which is against the securing of artesian water from the Paleozoic rocks is in the system of east-west faulting, shown in fig. 20 (p. 101), which probably affects the old rocks beneath the Tertiary and Cretaceous deposits. By this faulting all the rocks have been broken in two along certain lines, and the beds on one side or the other have suffered vertical displacement, so that the southward movement of the water through the water-bearing horizons is cut off at the lines of disturbance.

While the securing of artesian water from the Paleozoic horizon within limited distances from the highland border seems within the possibilities, the chances are against success.

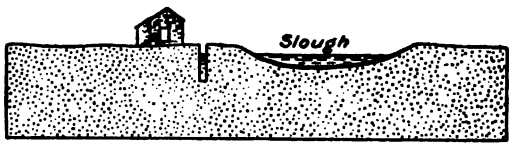

FIG. 31.—Well situated near an old slough.

SANITARY CONSIDERATIONS IN WELL SINKING.

Location of wells.—Too much care can not be exercised in the location of wells. Not infrequently are wells located on the borders of sloughs, the waters of which are stagnant in the summer season and are heavily charged with organic matter. Fig. 31 shows a well so situated. While these sloughs are always lined with very fine sediment that is largely impervious, more or less water is able to pass through it into the adjacent sand. The drawing of water from a well situated as shown in fig. 31, lowering the surface of the water in the well below that of the slough, invites the drainage from the slough toward the well.

In cases where, as a matter of convenience, it becomes desirable to locate a well near a slough, it should under no circumstances be an open one, and whether drilled or bored should go to such a depth below the bottom of the slough as to be out of reach of the downward-percolating, organic-charged waters.

When wells furnish water heavily charged with iron and organic matter the pipe should be "pulled" and driven elsewhere. As ex-

plained in another part of this paper, such water is probably due to the pipe being driven into a buried slough. Because of the concealment of the slough the location of good water can be determined only by experiment. Usually as good quality of water as the locality affords can be secured within a short distance of a well that supplies water of poor quality.

In no region should wells be located in barnyards or near other sources of surface pollution, except with intelligent advice. In a hilly region the surface drainage and stratigraphic conditions may be such as to permit a properly constructed well to be so situated; but in the lowlands of Arkansas, where there is but little, if any, surface drainage and the soil is porous, permitting the water freely to percolate downward, that practice can not be too strongly condemned. The watering places for barnyard fowls and the wallows for hogs are often immediately about wells from which water is used for drinking. Such disregard for sanitary conditions is excusable only among the most ignorant.

Depth of wells.—The usual depth of wells over the lowlands is from 15 to 40 feet. It might be accepted as a rule that the character of the water improves with depth, for the greater the distance from the surface the freer it is from surface contamination. As the sinking of wells within the region is such an easy matter, it would doubtless be advisable in most cases not to stop short of 60 feet, and to go beyond this depth would be better still.

In those cases where water is strongly charged with iron and organic matter a better quality may sometimes be secured by stopping short of the organic-charged bed, or, if not by this means, by driving on through it into the sand or gravel beds below.

In a few localities the surface sands are thick enough to form a permanent reservoir, and in such cases shallow wells can be sunk, which furnish soft water of excellent quality when not so situated as to be affected by sources of surface pollution.

Casing wells.—Next to the location and depth of a bored well the most important thing is the casing. The material most commonly used for this purpose in the lowlands is wood, evidently with the belief that the only object of casing is to prevent the well from caving in. Another and equally important object should be to keep out the surface water. For this purpose the wooden casing is wholly ineffective. The chief object of a deep well is to avoid the surface water, and unless the casing keeps out the surface water a deep well has no sanitary advantage over a shallow one. Besides, a wooden casing must in time decay, and by this means enough organic matter may be added to the water to produce serious results. The best casing is galvanized-iron pipe or tile carefully cemented at the joints.

Open wells.—Open or dug wells should never be used except where the greatest care is observed in the cleanliness of the surface for some distance about, and even then they are unsafe, as more or less surface water will find its way into them. When such a well is used the wall should be of stone or brick and not of wood, as is too often the case.

WATER RESOURCES OF THE PORTSMOUTH-YORK REGION, NEW HAMPSHIRE AND MAINE.

By George Otis Smith.

INTRODUCTION.

A hydrologic examination of the vicinity of Portsmouth Harbor was made by the writer in June, 1904. This work was done at the request of the War Department, and special attention was paid to the problem of securing satisfactory water supplies for the several forts at the mouth of Portsmouth Harbor. The geologic conditions which influence the water resources at these points were studied, and to obtain the best results it was found necessary to extend observations for about 10 miles northeast along the Maine coast. The results obtained in this investigation have been reported on in so far as they answered the direct purposes of the examination. The observations made in the course of this study and the conclusions based thereon are presented in this paper in view of the relation they bear to similar hydrologic problems in other parts of the coastal region of Maine. Elsewhere certain anomalous conditions prevail in the occurrence of ground water, and while each area may demand its own explanation, it is believed that the results obtained in the present study may be at least suggestive in the solution of the problems elsewhere.

The area discussed in this article extends from Portsmouth and Newcastle, N. H., to York Beach and Cape Neddick, Maine. Aside from the city of Portsmouth and the various villages in the towns of Kittery and York, the region has a special importance from the location here of the coast defenses and the extensive navy-yard, as well as the presence of a large summer population at several deservedly popular resorts. The question of an adequate and safe water supply thus becomes a vital one and demands thoughtful consideration.

SOURCES OF WATER SUPPLY.

The present water supply of the Portsmouth-Kittery region comes from three distinct sources—surface (lake or stream) water, ground water from surficial deposits, and ground water from rock.

SURFACE WATER.

The supply at the Kittery Navy-Yard best illustrates the first class, water from ponds on the western slope of Mount Agamenticus being piped by a gravity system into the town of Kittery and across to the navy-yard. Both in quality and quantity this supply is excellent.

GROUND WATER IN SURFICIAL DEPOSITS.

The city supply at Portsmouth belongs to the second class. Some 50 shallow wells have been sunk in the surficial deposits, and from this system of wells 1,000,000 gallons are reported to be pumped daily. The domestic supply for a great proportion of the farms in this region is of similar origin. Wells are dug to the surface of the water table, locations being selected where the water table and land surface nearly coincide. Thus the wells of this type are commonly very shallow, and in fact are often located on the edge of swampy areas. The quality of such supplies varies from excellent to very poor, and in most of the smaller surface wells the seasonal variation is considerable. A few general statements as to the surface geology of the region will serve to explain the nature of this second type of water supply.

Outside the limits of the larger river valleys, in which there are doubtless alluvial deposits of considerable thickness, the surface deposits are predominantly glacial till, with local accumulations of fine alluvium or swamp deposits. Stratified gravels and sands of glacial origin were noticed at only a few points, and these appear to be so local in their distribution as to have no special influence upon the movement of ground water. The cover of till is thin over large areas, and rock exposures are both large and numerous. In such areas, which may be said to be the rule in the town of Kittery, Me., swamps are of common occurrence, and much of the region is poorly drained by surface streams. The distribution of the till and the absence of any extensive deposits of stratified drift are the determining conditions in the occurrence of ground water in the surface zone. The supply from this source can draw from only a limited catchment area, and seasonal fluctuation must therefore be expected.

West of Portsmouth some excellent wells are reported, which derive their water from sand and gravel. Some of these are artesian, and the water is in this case under pressure because of impervious beds overlying the water horizon. This area was not visited, but is probably one of stratified drift, differing in this respect from the region under consideration. It is also true that artesian water from such deposits belongs rather to the type of supply described in the following paragraphs.

GROUND WATER OF THE DEEP ZONE.

General character.—The third kind of water supply in the Portsmouth-Kittery area is that obtained from the underlying rock. Water from this source differs from that of the two other classes in several important particulars, which will be discussed later. More than a score of wells in this vicinity have been drilled in the rock, furnishing examples of this type of underground supply of pure water. The depth of these wells, so far as figures are obtainable, varies from 27 to 275 feet, but inasmuch as they tap this water of the deep zone they may be classed together as deep wells.

The elevation of these wells ranges from 100 feet above sea level to approximately sea level. Their yield is also quite different, some being very successful, while a few were failures. Three of these wells in the town of York, which adjoins Kittery on the east, are artesian, and these will be described, as will the few failures and also several wells that are of especial interest from their location near the forts at the mouth of Portsmouth Harbor. Concerning several wells conflicting reports were heard, but the data given below were furnished by either the owners or the well driller, largely supplemented by personal observation at the wells and in the immediate vicinity.

Descriptions of wells.—The well on the place of H. E. Evans (now deceased), on the road between York Harbor and York Beach, was drilled in 1889 to a depth of 27 feet, with a diameter of 6 inches. Rock was encountered at a depth of 3 feet, and the principal source of water at 25 feet. This water rises 2 feet above the surface, so that the well is truly artesian. The flow is reported as 100 gallons per hour, and the water supplies two summer cottages.

The well owned by C. B. Moseley, and situated on the northwest side of Cape Neddick, was drilled in 1894, and like all the wells in this vicinity has a diameter of 6 inches. The total depth of this well was 28 feet, water being encountered at 27 feet. This water flows from the surface, and the supply is reported as 30 gallons a minute, that amount having been pumped for an hour, with the result that the water in the well was lowered 2 feet. This water supplies three houses, flowing into two lower on the slope, and being pumped into a third. The elevation of the well is about 40 feet above the sea level, and it is not far distant from the shore.

The well on the property of W. H. Wentworth, of York Beach, is located between the railroad and carriage road on Long Beach, and was drilled in 1889, to a depth of 70 feet. The well is located in a swamp back of the beach, and is approximately at sea level. The upper 16 feet was in mud and beach gravel, the remainder of the well being in solid rock, reported as "mostly trap." The water from this well rises 2½ feet above the surface, and the amount is reported by

the driller as 4,000 gallons per hour, without either diurnal or seasonal variation of the water level. The water is of excellent quality, and by means of a windmill is made to supply a boarding house and a number of cottages, twenty-five families being said to have been served by the supply.

The well on the grounds of Hotel Pocahontas, on Gerrish Island, about 20 feet above the sea level, is of special interest from its proximity to Fort Foster. This well was completed in 1895, being drilled to a depth of 40 feet, the principal source of water being at 39 feet, with other veins at 20 and 31 feet; the water stands 8 feet below the surface of the ground. The driller reports the flow to be 75 gallons per hour, although a much larger rating is given by the owner. The water is raised by a windmill, and partly supplies the hotel; another source of supply is a natural spring 7 feet above high-tide and within a few yards of the shore. This spring has been excavated in the rock to a depth of 8 feet, and when not pumped overflows through the crevices in the rock.

The most important well in the area is at Hotel Wentworth, on Newcastle Island. The well is situated at an elevation of about 40 feet on the southwestern end of this island, on the eastern shore of which are situated Forts Constitution and Stark. The well was drilled some years ago, and the total depth is variously reported, but is said by the agent of the Jones estate, by whom the property was owned, to be about 275 feet. It could not be learned at what depth water was encountered, nor how near the surface water rises. The rate of flow is not known, except through information secured from the manufacturers of the steam pump in position over the well, who state that a Deane pump of this type should pump 30 gallons per minute when working efficiently. The engineer in charge states that in the middle of the summer this pump has been run night and day for two weeks at a time, with no appreciable diminution of the supply. The quality of the water is excellent, and is used to supply a large part of the Hotel Wentworth. This property has several surface wells fed by the springs, which form an auxiliary supply, but as these fail in the height of the season the deep well may be said to be the only supply for the dining rooms and the larger part of the hotel, one wing of which is supplied by city water from Portsmouth.

A short description should be given of the few failures in this region. In the vicinity of the Evans well, on Cape Neddick, two unsuccessful wells were drilled. One of these was drilled to a considerable depth without any water being encountered, this case being especially remarkable from the fact that the hole was located only a few hundred yards from the artesian well. Another at a slightly greater distance from the Evans well was drilled to a depth of 87

feet, at which level salt water was encountered, which rose to approximately sea level. This well, it should be noted, was drilled in the gabbro which makes up the greater part of Cape Neddick, while the dry well was in schist close to the gabbro contact, and the Evans artesian well was in slate and schist, all of which rocks will be mentioned in the following paragraphs.

Another unsuccessful well was drilled at Fort Stark, under direction of the Corps of Engineers of the Army, to a depth of 260 feet. At 130 feet fresh water was encountered, but only in small amounts, and at 260 feet salt water was struck. The site of this drill hole is now concealed by the fortification. In the same vicinity, on the Barrett estate, a well was drilled to the depth of 150 feet, at which depth it had to be abandoned on account of the crooked drill hole. A small amount of water of excellent quality was encountered, but not sufficient to warrant pumping.

GEOLOGIC CONDITIONS.

The geologic conditions which control, or at least influence, the occurrence of this water of the deep zone must now be considered. The problem is not a simple one, but the following observations may serve to explain to some extent the well data given above.

LITHOLOGY.

The prevailing bed rock over this area is metamorphic in nature. Schists that evidently represent metamorphosed sediments, together with well-bedded slates and quartzites, underlie the greater part of the area. The strike of these rocks is N. 60° to 80° E., with N. 70° E. possibly the prevailing direction. The dip varies also within only narrow limits, being 75° to 90° either to the north or to the south, and more commonly vertical. At only one locality were low dips observed. At the outer entrance to Portsmouth Harbor the rock is more gneissoid in character, and to a large extent represents metamorphosed igneous rocks of an acidic type. In what proportion these igneous rocks were of volcanic and in what of intrusive origin can not be stated, but both types are doubtless present.

Cutting these old metamorphic rocks are numerous dikes of diabasic and basaltic rock. Some larger masses belonging to the same intrusion have more of the gabbro texture, and the outer portion of Cape Neddick, as noted above, is composed of very massive gabbro. These basic intrusives are relatively much younger in age, and it is noticeable that the basaltic dikes cut not only the schistose rocks, but also the quartz veins which traverse the schists and slates. Some of these dikes cut across the schistosity and stratification, following joint planes, but more commonly they are parallel to the bedding and might be more properly termed intrusive sheets.

JOINTS.

The essential feature for the purpose of the present discussion is that all these rocks, whether of volcanic or sedimentary origin, have been so thoroughly metamorphosed that the foliated structure is characteristic for all. These rocks are much jointed, although no regular system of joints could be recognized as prevailing for any distance. The intrusive rock is also jointed, a system of three joint planes nearly at right angles to one another being noted in the gabbro of Cape Neddick. In general it is probable, however, that the intrusive rock is jointed to a less extent than are the older schists and slates.

The question to what extent the joints in the above rocks represent open spaces is most important. The prominence of these joints on the weathered surface suggests that the rock mass is considerably fissured, but there is also reason to doubt this conclusion. At the southern end of the navy-yard very extensive excavations are in progress for the purpose of removing a point which projects into the river channel. An examination of the piles of broken rock from this source shows that the quartzite has very irregular fractures, which appear to be very largely independent of either stratification or joint planes. Many of the joint planes are also seen to have been cemented with quartz in thin films. A few small faults were noted in this region, but it is probable that these also are well cemented.

ZONE OF STORAGE.

Presence of artesian water.—The physical character of the rocks of the area and their structures are plainly quite different from those observed in typical artesian basins. The rocks are compact and well cemented, so that in no strict sense can it be said that there is present a pervious stratum between impervious strata. Neither is there any approach to a basin structure, but rather the structure is that of closely compressed folds, in which the strata are steeply inclined. However, artesian water is known to exist in this area, as proved by the artesian wells already described, and in the other deep wells which did not flow the water encountered is under static pressure, as evidenced by the rise within the well. Essentially, then, the water supply of these deep wells is of the artesian type—that is, the water rises within the drill hole for a score or more feet above the level at which the drill tapped its flow. This supply of underground water is therefore somewhat exceptional in type, and the conditions presented deserve further consideration.

Mode of flow.—As noted above, the water-bearing rocks are not porous in the same sense as most rocks which form the pervious beds in artesian basins. The water circulation can not be through pore

openings, but must be along the stratification partings, joint openings, and other less regular passages within the rock mass. It is difficult to state which class of these is the most important in governing the circulation of the water. The bedding and schistosity planes are of course the most persistent, although probably lacking the regularity and width of the joint openings, and from their approximately vertical position these partings would serve to conduct the water from higher to lower levels, and vice versa. Such of the joint planes as approach horizontality would furnish connecting passages between the vertical openings, yet how continuous such a system of openings is can not be stated, owing to ignorance of the extent to which these natural openings have been modified by cementation. It is believed, however, that the master joints of the area are nearly horizontal, so that movement of the water in the horizontal planes is less obstructed than the upward movement. The fact that the water tapped by the wells described above usually rises either to the surface and overflows the top of the well casing, or at least rises to a considerable extent within the well, indicates conclusively that there is static pressure and more or less confinement by the overlying rock.

If these joints and other partings were present throughout the rock mass, the essential condition of an impervious cover would be lacking and the ground water from the deep zone would escape at the surface. Two factors, however, appear to combine to prevent such natural escape except in rare cases like the spring near Hotel Pocahontas. The pressure under which the water circulates in the deep-rock zone is insufficient to overcome the internal friction within constricted openings in the higher parts of the zone of water circulation, especially as there is a greater degree of cementation along these upward-leading planes near the surface. This presumption of greater cementation near the surface is supported by the observations at the navy-yard excavations, as well as by the general theory of vein deposition. In view of the moderate depth of the three flowing wells, it may be true that this cementation is especially effective only to a depth of 20 to 100 feet, within which surface zone it may wholly stop water circulation.

The conclusion gained by this investigation is that the ground water in the deeper or rock zone circulates relatively slowly within the constricted natural openings in the rock. The water of this zone is contributed from distant areas rather than from the immediate vicinity, and the rate of circulation is so slow as to make the supply essentially free from seasonal variation. The elevation of the principal catchment area is not sufficiently great to cause the water thus flowing to be under great pressure—that is, the pressure is not usually sufficient to overcome the friction incident upon upward escape through the natural joint, stratification, or foliation planes, which

are more or less thoroughly cemented near the surface. In such exceptional cases as the spring near Hotel Pocahontas on Gerrish Island the water from the deep zone does thus escape, probably through a less constricted opening. In the artificial openings of the wells the water is provided with a free vertical channel, in which it rises for 10, 20, or possibly hundreds of feet, and in the case of the artesian wells cited actually overflows at the surface. The extent to which the water thus rises is therefore a direct measure of the amount of pressure under which it circulates at the point reached by the drill hole, a pressure, however, that was insufficient to overcome the frictional resistance to upward flow along natural channels in the rock.

Another feature which appears characteristic of the wells in this area is that the water circulation is more or less confined to trunk channels rather than equally distributed throughout the water-bearing zone. This is not simply because the water prefers the trunk channels, but because the rocks are so indurated and free from pore openings that these larger openings are the exclusive channels of flow. This is shown by the well logs, which indicate the presence of definite flows at different levels, which are not determined by the presence of definite porous strata, but more probably by the position of joint planes or other openings within the mass of steeply inclined and highly indurated rock. Further proof of this is afforded by the case of the Wentworth well, where the drill dropped 1 foot at the point where the principal flow was encountered. Such a distribution of the water circulation along a limited number of well-defined channels would explain the marked difference between wells located in the same vicinity.

PRACTICAL CONCLUSIONS.

With the results of this investigation in mind, some definite statements can be made that may be of practical value to anyone interested in utilizing the water from the deep zone of flow.

Water that is truly artesian, or that is at least under sufficient pressure to make it rise in a deep well, exists in the rock underlying the area under consideration. The distribution of this supply of underground water is such that a few failures may be expected among deep wells drilled in this area, but the percentage of failures should be very small if some judgment is used in the selection of the location for drilling. The logs of the most successful wells show that the depth at which the best flows will be encountered can not be definitely predicted. In most cases an abundant flow should be expected at a depth of less than 100 feet, but in some localities the drill might reach a depth of 300 feet before the water was encountered in good quantity.

The location of a few successful wells suggests some precaution to be observed. Inasmuch as the cracks showing at the surface ar not indicative of similar openings at considerable depth, they shoul not be considered as indicating that water-filled channels will b encountered by the drill with depth, and furthermore if such loca tion is near the shore the presence of such surface cracks increase the liability of encountering sea water, which has followed passage extending from the submarine rock surface. Again, in selecting a place for locating a well, it will be preferable to avoid diabasic dike and sheets which traverse the schist in many parts of the area Several successful wells in York and Kittery, however, appear t have been drilled, in part at least, through this intrusive rock, bu it seems probable that the schist is the better water-bearing rock, i that it contains more partings.

More specific conclusions have been submitted to the War Depart ment relative to the conditions at the various forts. The above gen eral statements, however, apply to practically all of the area describe in this article. Furthermore, it is believed that the application o these conclusions may be safely made over a larger area. Geologi investigation of other portions of the Maine coast during the sam season has led the writer to consider that the principles here formu lated regarding the nature of the deep zone of flow constitute a ten able hypothesis for the explanation of the hydrologic conditions i these other regions. In these areas of thoroughly indurated an closely folded rocks the joints are the structural elements most im portant in the control of underground circulation, and thus there exists a type of artesian storage quite different from the basins usually described.

A GROUND-WATER PROBLEM IN SOUTHEASTERN MICHIGAN.

By Myron L. Fuller.

INTRODUCTION.

General statement.—In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of Huron River, in southeastern Michigan, which up to that time had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes. Wide attention was attracted to the failure of the wells in the region, because the shortage was supposed to have been brought about through underground drainage by a powerful flowing well on Grosse Isle, a few miles to the east. Careful field investigations showed the improbability of such influence, the evidence indicating, on the contrary, the failure to be due to certain general causes of rather widespread application.

The explanation of the failure of wells in the region in question is similar to that in like districts at many points throughout the country, and it is with the object of calling attention to certain general factors, both temporary and permanent, which tend to induce a shortage of the ground-water supplies over large areas, that the present paper has been prepared.

Location of area.—The region in which the shortage of water in 1904 was earliest felt and in which it was severest is a belt perhaps 10 miles wide, extending in a northwest-southeast direction, parallel with and including Huron River from a point near New Boston, about 20 miles in a straight line above its mouth, to its juncture with Detroit River, 28 miles from Detroit. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. To the south the affected area is not only much broader, reaching a width of 7 or 8 miles, but the shortage was more pronounced, reaching a maximum along Swan Creek, which parallels Huron River at a distance of from 3 to 5 miles on the south. South

of Swan Creek the wells were affected only for a short distance, usually not over 2 or 3 miles.

The belt showing shortage lies in two counties, the relatively narrow strip north of Huron River being in Wayne County and the wider one south of the river in Monroe County. The villages principally affected are Willow, Waltz, Carleton, Flat Rock, and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

FIG. 32.—Rainfall map of Michigan.

Character of the country.—The entire region is characteristically flat, and, except in the vicinity of the streams, which have cut shallow channels for themselves, almost no inequalities recognizable by the eye are to be seen over large areas. The surface materials are generally clayey, although locally the clay may be overlain by thin sheets of sand, which in places takes the shape of low, flat, northeast-southwest ridges or terraces, representing old beach lines of the lake which

formerly covered the region. Although excessively flat, the country has a gentle slope southeastward toward Lake Erie, usually not exceeding 5 feet to the mile. The main streams—Huron River and Swan Creek—flow in the direction of greatest slope to the southeast, while the smaller streams, including the tributaries of the large streams named, flow either along similar southeast lines or converge slightly toward the main drainage lines.

The region is a populous one. Roads follow nearly every section line, and houses are abundant, there being frequently from ten to twenty to a section. The farms are correspondingly small, but are under careful cultivation, and the owners appear to be prosperous. Three steam railroads and a trolley line give frequent communication with Detroit and afford abundant opportunity for the shipping of produce.

Climate.—The climate of the region is tempered to a certain extent by the proximity to Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39°, the average maximum 57°, and the average mean 48°. The rainfall, which is about 30 inches, is low as compared with certain other portions of the State, where it may reach 35 to 40 inches. (See fig. 32.)

There are, however, considerable areas in which the precipitation does not exceed 30 inches. Normally the rainfall is lowest in January, when it is under 2 inches, and highest in May and June, when it is over 3½ inches per month. About the head of Huron River the rainfall is greater than along the lower part of its course and serves to keep the stream somewhat higher than would otherwise be the case.

GEOLOGY.

SURFACE MATERIALS.

Character.—The materials overlying the rock in the region consist largely of what is locally called "clay," but what is more properly a clay with an admixture of sand and pebbles. The materials are not usually arranged in definite layers as in stratified deposits, but commonly exist rather as heterogeneous mixtures, although occasional beds of quicksand or gravel, or even scattered bowlders, may occur. In consistency the material is tough and clay-like, grayish blue when fresh, but becoming yellowish through oxidation of iron on exposure to the weather at the surface. Some bowlders occur in the part of the area nearest Detroit River.

Thickness.—Although the superficial materials have a flat surface, their thickness varies from place to place, because of differences in elevation of the buried rock surface, which reaches much nearer to

the top of the ground in some places than in others. The clayey deposits are from 15 to 40 feet in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and in places have even cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface, as in the large quarries at Newport.

In a broad way, the thickness of the clays may be said to increase as Detroit River and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 35 feet, while near Rockwood the thickness may be as high as 40 feet.

Origin.—The surficial materials are of somewhat diverse origin. The bowlders and the unstratified materials were derived from the glacial ice which once covered the region, the accumulation taking place under the ice or very close to its margin during halts in its retreat. The waters at that time stood higher than at present, covering the entire area under discussion and reaching back as far as the base of the hills near Ypsilanti. In them a portion of the clays and the sand locally covering the surface was deposited as the ice retreated. Ice and water deposition were simultaneous and without sharp lines of demarcation, making it difficult to differentiate one from the other. After the retreat of the ice from the region the waters finally sank, with several halts at different levels, to their present position. During these halts the deposits were subjected to more or less washing by the waves, with the result that beaches were cut in the clay or constructed of sandy materials derived from it. These are the so-called terraces, ridges, or beaches extending in a northeast-southwest direction across the region northwest of the area under discussion and between it and Ypsilanti.

ROCKS.

General statement.—As was pointed out in the paragraph in which the thickness of the surface deposits was discussed, the rock surface is irregular as compared with that of the overlying clays, rising at points until it is within a few feet of the surface and again sinking 20, 30, or 40 feet below it. There are no great inequalities, however, and even if the soil were removed the surface would still be very regular, with elevations rarely rising more than 20 feet above the surrounding level. The irregularities are entirely independent of the present streams, which in the main have been determined in location entirely by the surface deposits. The rocks underlying the clays in the lower Huron River region consist of limestones, sandstones, shales, etc., arranged in belts extending in a northeast-southwest direction,

or at right angles to the course of Huron River. They are reached by all but the shallow wells and afford the greater part of the ground water found in the region.

FORMATIONS.

Dundee limestone.—In the northwestern portion of the area, or beyond a point a couple of miles northwest of Carleton, the rock is the Dundee limestone, a fairly pure, light-colored, flint-bearing Devonian limestone of perhaps 100 feet in thickness and dipping northwestward at a rate of 20 to 25 feet to a mile. It is characterized by waters more or less charged with sulphur in the form of hydrogen sulphide.

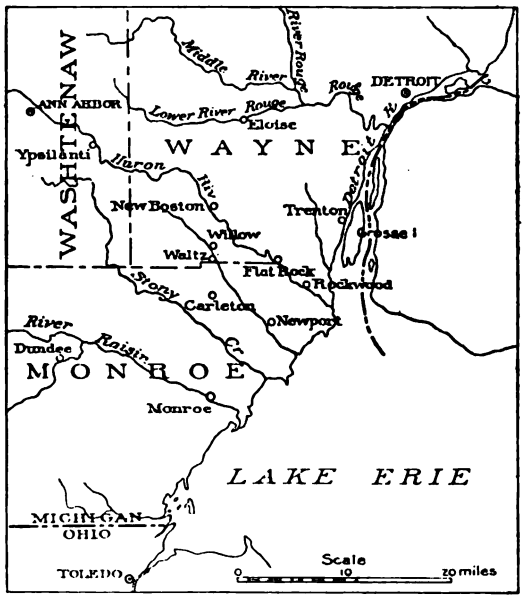

FIG. 33.—Sketch map of southeastern Michigan, showing area discussed.

"*Upper Monroe*" *beds.*—These are drab magnesian limestones, or dolomites, sometimes carrying sand and gypsum and other minerals. The dip is similar to that of the Dundee limestone. The waters are hard, but are not characterized by much sulphur.

Sylvania sandstone.—This is a white sandstone outcropping beneath the clay in the region at a point about a mile east of Carleton, nearly to the mouth of Huron River. The dip is somewhat flatter than those of either of the preceding formations and is more to the north than to the northwest. It yields water of a good quality.

"*Lower Monroe*" *beds.*—These are generally similar to the limestones and dolomites constituting the "Upper Monroe" beds already

described, but are often more siliceous than the latter. They outcrop parallel to the Sylvania sandstone in a narrow belt along Lake Erie and Detroit River. Their waters carry some sulphur.

WATER SUPPLIES.

PRESENT CONDITIONS.

The conditions as regards water supplies vary considerably throughout the region under consideration, the variations being marked by differences in composition, head, volume, and in the amount of shortage shown in the time of drought. Each of the individual areas will be separately considered.

WILLOW-EXETER REGION.

General conditions.—The term "Willow-Exeter region" is applied to the area now or formerly furnishing flowing wells, which extends from the vicinity of Willow southwestward past Waltz into Exeter Township, Monroe County, at its northeast corner. The area in this township is mainly included in secs. 1, 11, 12, 13, and 14, with parts in secs. 2, 10, and 15. The belt lies transverse to the drainage of the region and is located mainly over the outcrop of the Dundee limestone.

There are several types of wells in the district—dug wells, obtaining a very limited supply of nonsulphurous water from the clays; drilled wells, passing through the clay and penetrating the rock and obtaining strong sulphur waters, which will frequently flow at the surface; and a combination of the dug and drilled types uniting the characteristics of both. Such wells are usually dug for about 15 feet and continued thence by a small drilled hole down to the rock, which is usually penetrated for a foot or two. These wells are particularly adapted to those cases where the water will rise nearly, but not quite, to the surface. They furnish under such conditions admirable opportunities for storage and will ordinarily yield much more water than the simple pipe wells, which often show a strong tendency to become clogged when water is most needed.

The depth of the wells varies from about 15 to 35 feet, of which all but a foot or two is usually through the clay. The depth is least at the eastern limits and greatest at the western border of the district. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams or in sags of the surface that good flows are obtained.

Condition of wells in 1904.—An examination of the wells of the region shows a lack of uniformity of conditions. Several of the surface wells are reported dry, while in others the supply is the same as usual. No decrease is noted in the wells in the sandstone, and

most of the limestone wells, or those yielding sulphur water, show little if any material shortage, although a few reported losses, which in several instances were returned wholly or in part after cleaning. Some interference among the wells exists.

No evidence is afforded by the wells to show that there is any shortage, except such as would always accompany an unusually dry season. The moderate decrease due to drought has not been regular, but was first felt by the shallower wells or by those yielding small supplies, and last by the deeper and stronger wells. The shortage is naturally generally most noticeable in the flowing wells, in which a difference of a foot or two in head may determine whether they will flow or not. Shortage in previous years is reported.

The head of the water in relation to altitude declines from 622 feet above sea level in the western part of sec. 14, T. 5, R. 8, to 600 feet near the east line of sec. 19 of the next township east, or a little over 7 feet to the mile. This would indicate that the source of the supply was to the west, probably in the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of nonflowing wells lying between the Willow-Exeter and the Swan Creek flowing-well districts. The wells are commonly about 30 to 35 feet deep and probably enter for a few feet the Sylvania sandstone, from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August, although the wells were somewhat lower than usual.

SWAN CREEK REGION.

General conditions.—This is a region of flowing wells extending along the valley of Swan Creek from near the Detroit Southern Railroad, 1½ miles northeast of Carleton, southeast to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron River and Rockwood districts of flowing wells. The area is mainly over the outcrop of the Sylvania sandstone.

The wells are of the dug, drilled, or dug and drilled types. Except those of the first type they all obtain their water on entering the rock after passing through the stiff impervious clays. The wells have hitherto always yielded good flows of nonsulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

Condition of wells in 1904.—As in the Willow-Exeter region, the behavior of the wells is not uniform. In the Swan Creek region,

however, nearly every well shows shortage, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very uniformly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while others, though still running, rise to only a part of their former height. In the non-flowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued along the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly again in the spring of 1904. At just what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Supposed causes of shortage.—Nothing could be more variable than the opinions presented as to the cause of shortage. The most general of the explanations attributed the loss of water to subterranean drainage by a deep-rock well located at the southern extremity of Grosse Isle and flowing at the rate of a barrel a second. Credit was given to this supposed cause by many who would not otherwise have thought of it, because of the fact that one or two of the wells near Rockwood ceased to flow temporarily in the fall of 1903 only to begin again a short time after, and to continue until the spring of 1904, when they again ceased. These changes are said to have coincided, respectively, with the striking of the water vein, insertion of casing, and, finally, with the withdrawing of the pipe from the Grosse Isle well.

Others, however, see no connection with the Grosse Isle well, attributing the shortage to lack of rainfall, the frozen condition of the ground when the rains of the previous autumn fell, the extensive ditching of the land in recent years, and the consequent increase of run-off as compared with absorption, and to drainage by the quarry at Newport. All are possible causes and were investigated with the view of finding the determining factor.

Steps taken to increase supplies.—Several methods of remedying the shortage were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening of the well was resorted to. In some cases the dug part was carried a few feet deeper,

and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective results were obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although, of course, it had to be pumped to the surface.

HURON RIVER REGION.

General conditions.—This district extends along Huron River from a point a mile or two southeast of New Boston downstream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The rock is largely Sylvania sandstone, except at the northern end of the district. The wells, as in the previous districts, are of the dug, drilled, or dug and drilled types, and range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water without sulphur.

Condition of wells in 1904.—In a broad way it may be said there is a general shortage of water in the region, but that it is not so severe as in the Swan Creek district, for along the Huron many wells still furnish good supplies of even flow, while in the latter region the failure is almost universal. The causes ascribed for the shortage are similar to those of the Swan Creek area, but with less weight given to the supposed influence of the Grosse Isle well. Cleaning and, more especially, deepening the wells generally resulted in an improvement in the conditions.

ROCKWOOD REGION.

General conditions.—The Rockwood area includes the region west and southwest of that town and between it and the Swan Creek area, together with the region near the town on the north side of Huron River. It can be considered as merging into the flowing-well areas of Swan Creek and Huron River on the west and into the Detroit River region on the east. The area is mainly over the outcrop of the Sylvania sandstone and yields waters generally free of sulphur. The wells are generally from 20 to 40 feet in depth and are nonflowing, except near Huron River.

Condition of wells in 1904.—The field work showed a marked shortage of supplies with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903, when the present shortage first began to be felt. During the winter of 1903–4 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the

individual wells stopped suddenly, the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head, hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest west of Rockwood, becoming less as the town and Detroit River are approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

Supposed causes of shortage.—The explanations of the shortage are the same as in the Swan Creek area, with special emphasis on the Grosse Isle well and the Newport quarry. On both of these supposed causes, however, opinions are divided, those not believing in their influence being as positive as those favoring such interference. It was noticeable, however, that the belief in both the quarry and deep well became less firm the nearer they were approached, being held rather by the owners of more distant wells than by those of the nearer ones.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and the shores of Detroit River. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, quite thickly settled and wells are abundant, but probably average under 20 feet in depth. In general there has been no trouble with shortage of water, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was as high as or higher than is ordinarily the case, as Lake Erie, which controls the ground-water level adjacent to its shores, stood about 15 inches above the normal in the summer of 1904.

GROSSE ISLE.

General conditions.—Grosse Isle is a north-south island about 9 miles long and 2 miles wide, lying on the American side of the international boundary in the Detroit River, its center being opposite the town of Trenton, 18 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being situated in the interior, notwithstanding the entire island is under cultivation. The surface is mainly clay or clayey silts, but

rock is commonly found not far from river level and in one point, where it rises slightly higher, is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of windmills, no provision being made for filtering. There is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and no one had observed the slightest effect due to the big well at the southern end of the island.

Grosse Isle or James Swan well.—This well is located on the property of James Swan, opposite Snake Island, about three-fourths mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the level of the river in 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet, but at 450 feet a bigger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart a considerable amount of sulphur to the water as it issues from the pipe, and to be recognizable by taste and sulphur deposit on the grass and stones about the well.

Analysis of water from James Swan well, Grosse Isle.

F. K. OVITZ, analyst.

[Parts per million.]

Silica	188
Calcium oxide	7,616
Strontium oxide	376
Magnesium oxide	1,212
Sodium oxide	292
Potassium oxide	112
Sulphuric anhydride	11,871
Chlorine	248
Carbon dioxide	1,550
Iron and alumina	14
Loss on ignition	2,006
Total solids	25,485

The water is said to have been cased off during the progress of the drilling, from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable size. (See Pl. IV.) The flow is calculated at about 50 gallons per second and forms two sizable streams as it flows away from the well. The water was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using the water for a public supply for the island.

SUMMARY.

The conditions of the wells at the present time have been described in detail in the preceding pages. With the exception of the narrow belt along the shore of Detroit River, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very slight, while along Huron River it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large proportion of the wells going dry and entailing much inconvenience.

DECLINE OF THE SUPPLY.

HISTORY.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even the shrinkage of supplies had been in progress for many years. In his report on Monroe County,[a] he states that while continued drought makes no impression on many of the wells, the flow of others is reduced, or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian waters could be secured were found to be becoming constantly more contracted. Wells in the southern part of Erie Township, back 3 miles from the lake, which formerly flowed, had then ceased.

The decline, noted by Professor Sherzer as having already progressed for some time, has continued to the present time. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the nonflowing wells is lower than formerly. In fact, the level of the ground water in the clayey portions of southeastern Michigan

[a] Geol. Survey Michigan, vol. 7, p. 194.

A

B

VIEWS OF THE GROSSE ISLE, MICHIGAN, FLOWING WELL.

is distinctly lower than it was ten years ago, and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline, which has been going on for many years, is probably due to a gradual and far-reaching change of conditions the nature of which will be considered on subsequent pages; but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

CAUSES OF THE DECLINE.

GROSSE ISLE WELL.

General statement.—It is this well which has most frequently been assumed as a cause of the shortage of water in the region under discusion. That it can not be the sole cause is readily shown by the fact that the decline had been going on for many years before its sinking

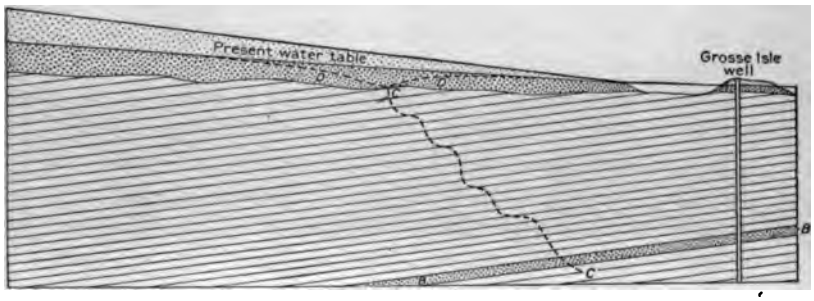

FIG. 34.—Actual and theoretical positions of water table. *B*, Water-bearing bed of Grosse Isle well; *C*, theoretical crevice leading from surface to water-bearing bed; *D*, depressed form which water table would have if water was being drawn into the rocks through crevice *C* in sufficient quantity to affect wells.

in 1903. That it might be the cause of the special decline in that and the following year did not, however, appear unlikely at first, a special argument being afforded by the behavior of the wells of J. E. Brown, etc., of the Swan Creek, and of Charles Bancroft, etc., of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned coincident with the insertion of the casing, only to cease again after its withdrawal in May, 1904. There are, however, many facts which seem to show that the shortage has no connection with the Grosse Isle well.

Districts affected.—The investigation made by the writer showed, as has been described, that while wells in the Swan Creek and Rockwood districts ceased flowing or failed to yield their usual supplies, other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be

very exceptional which would leave a near-by district unharmed while seriously affecting more remote districts.

Slope of water table.—With a view of determining the source of the water of the Swan Creek-Rockwood area, the head, or height to which the water would rise, was plotted for each well in the region. It was found that this head showed an increase going west of about 3 feet per mile, indicating a source in the hilly region to the northwest. The increase of head to the west (or decrease to the east) was regular, there being no local lowering with a reversed slope downward toward the rock such as would be present if the water was being drawn down into the latter through a fissure connecting with the stratum furnishing water to the Grosse Isle well (see fig. 34).

Geologic structure.—The precise point where the main water-bearing bed of the Grosse Isle well outcrops and whence its supply of water is derived can not be stated. The rocks incline regularly to the northwest (or rise to the southeast) at a rate of perhaps 20 feet to the mile. On the basis of this dip it would seem probable that the bed, which has a depth of 450 feet at the well, would come to the surface somewhere west of Leamington, Ontario. In the Huron River region, however, it would be even deeper than at the well, probably being, in the vicinity of Carleton, nearly 800 feet below the surface. The chance of there being any fissure through all this thickness of strata, by means of which connection between the deep-water beds and the surface wells might exist, is very slight. On the other hand, water can pass downward along the bedding planes with the greatest ease. Such is probably the case, the water being derived from the Ontario region rather than on the American side of the river.

Volume.—A strong impression is left on the mind of one visiting the Grosse Isle well by the immense volume of its flow, which is calculated to be between 45 and 50 gallons, or over a barrel, a second. When, however, it is recalled that the region in which the failure of the wells has been attributed to Gross Isle hole has an area of over 100 square miles, it will be seen that the amount which could be taken each second per square mile is not over half a gallon, or less than a thousandth part of a gallon per acre. The amount ordinarily taken from a square mile by the flowing wells of the Swan Creek and Rockwood districts was much more than this; in fact, the taking of a thousandth part of a gallon per acre each second would probably not have made noticeable effect on the flows.

Head.—The most convincing reason why the Grosse Isle well can not have affected the Swan Creek-Rockwood wells lies in a comparison of the heads of the water in the two localities. The head of the Grosse Isle well is 25 feet above lake level, or approximately 597 feet above sea level, while that of a considerable number of the Swan

Creek and Rockwood flows is less than this amount. In other words, the head of the Grosse Isle well is greater than many of the wells under discussion, and the water, if any connection existed between the two, would not be drawn from the shallow wells, but rather forced up into them.

Summary.—The evidence at hand gives no indication of any connection between the shortage of the shallow wells and the flow of the big Grosse Isle well, but affords, on the other hand, many indications that none exists. The supposed connection with the Grosse Isle well of the loss of water in the Brown and Bancroft wells in 1903 is the result of mere coincidence, the failure simply happening to take place at the height of the dry season of that year. That they should have failed in the still dryer season of 1904 was to be expected. The conditions were almost certainly local, as other wells in the vicinity were not similarly affected at the same time.

NEWPORT QUARRY.

The underdrainage caused by the quarry was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions investigated.

The quarry is located just east of the tracks of the Lake Shore and Michigan Southern Railroad at Newport and a few feet north of Swan Creek. The quarry is 200 to 300 feet across and is excavated to a depth of 18 feet in the limestone, which is reached after 10 or 15 feet of stripping. The creek flows on top of the rock surface, 18 feet above the bottom of the quarry, and is separated from the excavation by a small dike. Water enters at various points in small amounts, but is easily removed by pumping at a rate of about one-half a gallon a second (4-inch pipe, one-half full, but ejected with slight force). A part of the wells near at hand have been affected, but the decrease in the water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted.

The small amount of water entering the quarry is in itself an indication that no extensive area is being drained, while the fact that only a part of the adjacent wells are affected, while those a short distance away are unaffected, shows that even in its vicinity the quarry may be neglected as a factor in the shortage of the water supply.

DEFORESTING OF THE LAND.

The existence of forests in a region, while not affecting the amount of water falling on the ground, tends to prevent its escape into the streams with the rapidity with which it runs off of nontimbered

lands. By holding it back, even for a few hours, considerably greater quantities are allowed to soak into the ground than would otherwise be the case. Evaporation from the surface is also retarded, the ground remaining wet for much longer periods in wooded than in unwooded lands. The cutting of the timber must, therefore, be accepted as a factor in the general decrease of the supplies of the region. This, however, was effective only in the earlier days; it can not be considered as one of the immediate causes of the sudden shortage of 1903–4.

DRAINAGE BY DITCHES.

The region under discussion is exceedingly flat, and, because of its clayey soil and poorly developed stream system, was originally poorly drained, the low sags often holding water or remaining wet for long periods. All this has been gradually changed through drainage by ditches, with the result that much land has been reclaimed. The process, however, has not been without its drawbacks, for the ditches rapidly carry off much of the water which had previously soaked into the ground to become a part of the ground-water body. The result has been a gradual depletion of the ground water, especially within the past few years, so that the beginning of the present drought found an inadequate reserve supply in the ground.

DRAINAGE BY STREAMS.

The level of streams generally determines that of the ground water in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron River and Swan Creek were unusually low and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. Huron River, being a longer stream and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which falls within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is marked along its course rather than in any other part of the region.

EARLY FROST OF 1903.

This appears to have been an important factor in bringing on the present acute shortage. According to the official records, the permanent freezing of the ground took place on November 17, which was before the heavy autumn rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and spring months. This was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the ground water was at an unusually low stage.

DEFICIENCY OF RAINFALL IN 1904.

Because of the fact that the ground was frozen during the autumn and winter, the ground was in much the same condition at the opening of the spring of 1904 as it was at the end of the preceding summer, and as month after month during the present summer went by with deficient rainfall the shortage began to be severe. The shortage of rainfall in 1904 is brought out by the climate and crop-sowing reports of the Government, which show that from the opening of spring until July the rainfall was only from one-eighth to a little over one-half of the usual amount. Late in July and in August considerable rain fell, but as it came largely as short, heavy showers the water, instead of soaking into the ground as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell.

CONCLUSIONS REGARDING SHORTAGE.

No evidence was found to show that the Grosse Isle well had affected any of the wells whatever, nor that the Newport quarry was a factor in the failure of wells other than those situated within a few hundred feet of it. The deforesting of the region has been a factor in the general decrease of supplies in the past, but had no immediate connection with the present shortage. The ditching of the region was a prominent factor in the gradual depletion of the ground-water body, so that when the usual fall rains were prevented by frost from being absorbed and the winter was followed by a summer of exceptional drought, the conditions were ripe for the failure of water that followed.

FUTURE PROSPECTS AND REMEDIES.

The failure of the wells being due largely to the severe drought of 1903–4, it is probable that the return to the normal rainfall will result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or, perhaps, a succession of wet years, occurs.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey materials when dried out may, to a certain extent, crumble and become more or less clogged so that their capacity for carrying water is lessened or destroyed, even when the ground again becomes soaked. The return in any case will

probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

The wells in the lower Huron River region obtain their supplies in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more or less jointed and open portion of the rock, because there is less resistance to its flow through such crevices and openings in the rock itself than through the compact clayey deposits which generally overlie the rocks of the region. In its passage the water takes up sulphur and other mineral matter contained in the rock, its quality thus being changed from its relatively pure condition when it first left the drift.

It has been shown in the discussion of the wells of the region that a deepening has almost invariably met with at least partial success, especially where the wells have been sunk deeper into the rock. Throughout the entire region, however, the wells are unusually shallow, even for the surface-water type, a depth of 50 feet being exceptional. In many other regions in Michigan nothing is thought of going 50 to 100 or 150 feet in search of water. It is almost certain that wells of such a depth would in the lower Huron River region yield permanent supplies. Until such wells or at least wells entering some distance into the rock are sunk, a supply adequate to the demands in times of drought can not be expected.

APPLICATION TO OTHER REGIONS.

The history of the decrease of the water supply in southeastern Michigan is in many particulars identical with that in many other parts of the country where similar conditions exist. It is but one of the many striking examples of the failure of the water supplies which have attended the development of new regions, and its history may therefore be taken as a type.

Although the immediate failure of the wells in this, as in most other regions, was due to a deficiency of rainfall, many agencies tending to reduce the reserve supply of ground water had been working unobtrusively, but none the less surely, for a long series of years, with the result that when the precipitation failed to come up to its normal amount a severe shortage was immediately felt.

Probably the most general cause, or at least the one which has been active for the longest period of years, is the deforesting of the land, the result of which has been to increase the immediate run-off and the amount of evaporation. The factor is one which developed gradually, almost inappreciably, but none the less inevitably, as the

country became older and the forests necessarily gave place to farms. It is an unavoidable incident in the growth of the country.

Next to deforesting one of the most common causes of the decrease in ground-water supplies is the drainage by ditches. Much of the finest land of our country lies along the flat flood plains of our great rivers or on broad, flat plains, as in Ohio, Indiana, Illinois, and some of the more western States. Considerable portions of such flat lands were originally ill drained, water perhaps standing for months in the flood plains of the river bottoms or in the numerous shallow but often broad sags of the almost equally flat uplands. Thousands of acres of such lands have been, as time went on, gradually reclaimed by drainage ditches and now form some of the richest and most valuable land in the country. Almost everywhere, however, as has been pointed out for the southeastern Michigan region, the ditching has resulted in a decrease of the ground-water body because of the rapidity with which the rain water is removed, it having much less opportunity than formerly to soak into the ground and become a part of the underground supply.

As in the case of the cutting of the forests, the loss of water due to the increase in the number of the drainage ditches is inevitable. But it need not, in most cases, entail any great hardship, for, as in the Michigan region, the ground-water supply is not often exhausted, but simply lowered, and an increase in the depth of the wells usually results in obtaining adequate supplies. It is seldom that the depth will be so great that the cost of wells will be prohibitive to the ordinary farmer.

A further point of interest brought out in connection with the investigation of the southeastern Michigan region is the effect of early frost in helping to bring about conditions of shortage. It is readily seen that no matter how great the rainfall on frozen ground, but little will be absorbed, and if the frost occurs before the autumn rains a heavy precipitation may be without result as far as the ground-water body is concerned. This is a factor which may occur in most of our Northern States at any time, and one which must be taken into account in any investigation of shortage.

WATER SUPPLIES AT WATERLOO, IOWA.

By W. H. Norton.

INTRODUCTION.

The investigation of the conditions at Waterloo was undertaken in response to requests from various officials and drillers. Those from the city authorities were due to an epidemic of typhoid fever, which had raged for several months. Since the 1st of October, 1908, when the epidemic had become so pronounced that all cases were ordered reported, there had been up to March 29, as I was informed by the mayor, 310 cases of typhoid, 35 of which were fatal. As the population of Waterloo is 16,000, the death rate from typhoid for these months alone was 219 to the 100,000, or about 20 per cent higher than the annual typhoid death rate in the Chicago typhoid epidemic of 1892.

The location of the typhoid cases, as platted by the city engineer, showed that they were distributed impartially over the entire water district. The few cases in homes that lay outside the district could be explained by the use of city water in school or workshop. The cases were distributed on all the five sewer-drainage areas of the city, and the theory that the epidemic was due to a clogging of certain sewers was untenable. Dust and flies as possible causes were excluded by the continuance of the epidemic unabated into and through the winter, and it was far too widespread to be due to the infection of milk or foods. Excluding these not uncommon sources of the disease, nothing remained but the city water supply, which was drawn from Cedar River and treated by mechanical filtration.

The intake of the supply is situated a short distance above the town, below the mouths of two small creeks, one of which drains a portion of the suburbs. Five or six miles up valley the sewage of Cedar Falls, a town of 6,500 inhabitants, discharges into the river, and within a very few hours at most reaches the intake of the Waterloo waterworks. During the winter this sewage is protected from oxidation on even this short journey by a cover of ice. Under these circumstances, whenever there are one or more cases of typhoid at the

neighboring city the safety of Waterloo must depend solely upon the continuously efficient working of the filtration plant and the destruction by its coagulants of the noxious bacteria in the sewage-contaminated river water. An examination of the water made by Professors Albert and Beirring, of the University of Iowa, showed that not only the raw water of the river, but also the water after treatment at the filtration plant, was highly infected with micro-organisms, the colon bacilli being found in great numbers, and even the bacillus typhosus being recognized. The investigation of the workings of the filtration plant had shown that no tests were made of the amount of coagulants needed from time to time with the varying turbidity of the river, that the pipes through which the coagulants were admitted were sometimes clogged, and that the capacity of the filters was overtaxed by any demand beyond the usual daily consumption. During the epidemic there had been two occasions when the mains had been flushed at times of fires with water drawn directly from the river.

It was under these circumstances that the city officials asked for information from the United States Geological Survey as to the possibilities of other sources of supply than that now in use. They also employed as consulting sanitary and civil engineer Prof. A. Marston, of the Iowa State College of Agriculture and Mechanic Arts. As Professor Marston had already begun at the time of my visit to Waterloo a thorough investigation, and as he is advising with this Office, it seems unnecessary for me to make any specific recommendations as to the relative merits of different sources of supply or as to the methods of their utilization.

There need be considered, then, only the geologic conditions affecting ground and artesian water at Waterloo.

WATER SUPPLY.

GROUND WATER.

Waterloo is situated on a broad, ancient flood plain, which lies about 20 feet above the present river, and, up valley from the city, reaches more than a mile in width. Underlying the plain at a depth usually of not more than 20 feet is a floor of Devonian limestone. Where exposed to view the rock is shattered and closely jointed. Ground water, therefore, sinks readily through its surface layers to lower levels. The alluvium which has been spread over this valley floor of planation consists of sand and gravel, with some finer waste, and is the valley train of one of the Pleistocene ice sheets. Because of its loose texture, its ready drainage into Cedar River, and the pervious rock floor on which it rests, this broad terrace seems to contain

no large store of ground water. On some farms of 80 acres, for example, there has been difficulty in getting a stock well, seven or eight attempts having been made before success was reached. The outlook for a supply of water from this source appears unfavorable, but a careful investigation of all its possibilities is being made by Professor Marston and by Mr. C. T. Wilson, the city engineer.

SPRINGS.

About 5 or 6 miles up valley strong springs rise from the limestone on both banks of the channel of Cedar River. On the right bank copious springs gush from crevices for several hundred feet along the bed and near the mouth of Dry Run, a tributary of the Cedar. At the time of my visit to the place the run was ponded by high water in the river and was filled by clear spring water, in distinct contrast with the muddy water of the trunk stream. Notwithstanding the high stage of water, the springs in two places made a noticeable mounding of the water surface. A few feet above these springs are the strong springs used by Cedar Falls for its water supply. On the left bank of Cedar River, about half a mile from the springs just mentioned, two groups of springs are found along a distance of about 500 yards. These were largely concealed from view at the time of my inspection by high water from the river, and I am told are not so strong as those of the right bank. The discharge of all the springs will be carefully measured when the stage of water in the river permits, and their availability will be considered, either as a sole supply or as a partial supply in connection with artesian wells.

ARTESIAN WELLS.

Geology of region.—Waterloo lies in a region whose geologic structure is well known through the work of the Iowa Geological Survey and the surveys of adjoining States. To the depth of several thousand feet the underlying rocks consist of alternating beds of limestones, sandstones, and shales whose general dip is southwestward. These beds thus come to the surface in successive belts toward the north and east, even the lowest of the series appearing as the country rock in central Minnesota and Wisconsin. Several of these beds are porous sandstones. Into these water soaks in large quantities in the areas where they form the country rock, and through them it slowly seeps for hundreds of miles and to depths of several thousand feet. These pervious layers are sheathed, in several instances, with impervious shales, and when tapped by the drill their waters, which are under hydrostatic pressure, rise toward the level of their sources in the higher ground of the States bordering Iowa on the north and

northeast. The water may fail of reaching the surface, or on lower ground may overflow, but in either case the well is known as an artesian well. The geologic structure of the deep-lying rocks at Waterloo, on which its artesian conditions depend, is shown in the following section, which, though hypothetical, at least in the thickness assigned the different formations, is believed to be a close approximation to reality.

Hypothetical section at Waterloo, Iowa.

	Thickness.	Depth.
10. Devonian limestone and shales	125	125
9. Niagara limestone	135	260
8. Hudson shales	165	425
7. Galena-Trenton limestone	410	835
6. St. Peter sandstone (50–100)	80	915
5. Oneota limestone	400	1,315
4. Jordan sandstone	100	1,415
3. St. Lawrence dolomites and shales	200–400	1,600–1,800
2. "Basal sandstone"	Indeterminate.	
1. Algonkian quartzite or schist	Do.	

Water horizons.—The texture and conditions of each of these great formations remain to be considered.

The Devonian and Niagara limestones carry water only in their widened joints and crevices. The finding of any considerable amount of water in these beds is an accident whose probability is so slight that it may be neglected. Whatever water they may contain is under less head than that of lower horizons. Their waterways, if struck, would therefore lead off water from below instead of adding to it, and these rocks should be cased off.

The Hudson shale is dry. It is of importance to us because it forms an impervious bottom to the overlying formations and especially because it prevents the waters of the rocks beneath it from rising to the surface under hydrostatic pressure and being lost.

The Galena-Trenton, especially where a dolomitic or magnesian limestone, contains some artesian water in its crevices and fissures. Frequently its water is charged with sulphurous gases which soon escape on exposure to the air. The basal layers of this formation are often shaly and keep the waters of the underlying sandstone from escaping upward.

The St. Peter sandstone is the first important and dependable water-bearing formation of the series. Its grains are smooth and rounded and often but slightly cemented and the pore spaces of the rock are

considerable. The capacity of the sandstone varies with its thickness and texture and these can not be predicted with any closeness. The St. Peter may range from 50 to 100 feet in thickness.

The Oneota is a creviced sandy limestone. While the drill passes through it the flow will probably be strongly reenforced from its fissures and sandy seams.

The chief water-bearing stratum of the series is the Jordan sandstone, the upper member of what has been known as the St. Croix, or the Potsdam. Its normal thickness is about 100 feet and its texture resembles the St. Peter. It is recommended that any artesian wells which may be sunk at Waterloo be carried to this sandstone.

The St. Lawrence dolomites and shales, which underlie the Jordan, are usually dry. Their normal thickness is about 200 feet, but they may be found to double that amount at Waterloo.

The "Basal sandstone," as the Iowa Survey has termed the lowest member of the Potsdam formation, is a deep bed of sandstone, more or less limy or clayey in places and in many of its layers so close textured as to be impervious. Toward the east and north, where it lies nearer the surface, its open textured layers are more numerous and thicker, and here its supplies of water are both more abundant and less heavily mineralized than toward the west and south, where it descends deep below ground and where its grains have been more firmly cemented. The thickness of this sandstone at Waterloo can not be predicted. It probably is greater than 200 or 300 feet and possibly, though not probably, may reach 1,000 feet, its thickness depending on the irregular relief of the Algonkian floor whose inequalities it covers.

It seems probable that the increase in supply from the water horizons of the Basal sandstone would not repay the additional cost of penetrating them and that their waters would be more heavily mineralized than those of the zones above, and perhaps be salty, thus lowering their value for manufacturing purposes. But as at Waterloo the amount of water obtainable is of prime importance, I should advise, if an artesian system should be decided upon tentatively and an experimental boring should be made, to sink this boring not only the 1,400 feet needed to test the capacities of the chief zones of flow—the St. Peter, the Oneota, and the Jordan—but also to drive the well to as much as 2,500 feet, if the Algonkian is not sooner reached, in order to probe deeply the Basal sandstone and to test its water resources here.

Quality of artesian water.—Deep wells, if properly constructed, are practically free from possibility of contamination. Artesian water is organically pure. Communities which use it need not fear the widespread epidemics of such diseases as those whose germs are

carried in drinking water and which may visit cities using surface-water supplies because of conditions which can not always be foreseen and prevented.

In its long journey underground artesian water has taken up various minerals in solution, and at Waterloo the artesian water will be found less pure from a mineral standpoint than river water. It may be expected to contain in solution lime and magnesia carbonates, with some lime sulphate, together with the sulphates of magnesia and of soda. It is not at all probable that these minerals will be in quantities sufficient to render the water in the least unpalatable or injurious to the health, but several of them form scale in boilers on the evaporation of the water, and their amount in the artesian water found at Waterloo will probably be large enough at least to rank it as "poor" steam water (20 to 30 grains of incrusting solids to the gallon), and still more probably as "bad" steam water (30 to 40 grains of incrusting solids to the gallon). Possibly the water may carry its own "boiler compound" in minerals which will cause the injurious compounds to be thrown down in boilers mostly as sludge.

In a city like Waterloo, which has extensive manufacturing interests and anticipates a large industrial growth in the future, the hardness of artesian water is a serious drawback to its use as a city supply. In certain manufactures, such as ice factories, paper mills (if the water is free of iron), breweries, and bottling works artesian water may be preferable to surface waters, but for locomotives and the boilers of all manufacturing plants it is inferior to the supply now in use.

Quantity of artesian water.—Waterloo is a rapidly growing town with a population estimated at 16,000, and the needed daily water supply is placed by the city officials at 3,000,000 gallons. It is by no means certain that this large amount can be obtained from deep wells. It must be remembered that while the water stored in the water-bearing strata of the artesian field in Iowa is enormous, beyond the possibility of exhaustion, and the large intake area and its abundant rainfall insure its replenishing despite all drafts which may be made upon it, the amount of water which can seep through the sandstones at any locality is strictly limited, and the supply may be overdrawn at that place. At the best a 6-inch artesian could hardly be expected to furnish at this locality more than 250 to 300 gallons per minute. It may very probably not much exceed 200 gallons, and local causes which we can not anticipate may prevent the discharge from reaching 100 gallons a minute. At 200 gallons a minute, or 288,000 gallons a day, 10 wells would not quite give the required amount even if there were no mutual interference of the wells. It is taken for granted that interference will be made as little as possible by stringing the

wells on a line normal to the hydraulic gradient and as far apart as possible consistent with utilizing their discharge. But, with all that can be done, there will be interference, and more than 10 wells will be needed to yield 3,000,000 gallons daily, even if the discharge of a single 6-inch well, the others being closed, should reach 300,000 gallons per diem.

Necessity for test wells.—If it should be thought best to use artesian wells for city supply, it would be advisable to put down an experimental boring. If the flow should be meager, the well could be utilized for park, school, factory, or its water run into the reservoir of the waterworks. If the yield should be generous, the work of sinking other wells should yet proceed with caution. The flow and head of each successive well will indicate the approach of the limit where interference may finally make the sinking of other wells unprofitable. The city should be prepared to find this limit before the desired amount of water is obtained and to deal with the case accordingly. To a certain extent the supply may be increased by deep pumping, or by what has the same effect—an air lift. Torpedoes are sometimes used, especially in the case of oil wells, and if this experiment were to be tried the Oneota limestone would be a suitable horizon.

Head.—The head of artesian water at Waterloo is enough to give flowing wells on the level of the flood plain on which the town is built. Wells may therefore be drilled wherever convenience may dictate. An estimate of a head of 20 to 30 feet above the datum just mentioned, while a rough one, is perhaps sufficiently close for practical purposes.

Decrease of flow.—The permanence of an artesian supply is an important factor. Artesian basins when limited in extent are sometimes overdrawn as a whole and the head of water greatly lowered. This cause of decrease or failure need not be considered in connection with so large a field as that of the upper Mississippi Valley.

The local area is frequently overdrawn by a large number of wells, even when the general field shows no sign of decrease. In the case of Waterloo it is assumed that the number of wells sunk will be kept well within the limit of mutual interference. It is assumed that the flow of water through the pervious water-bearing strata to the local area will be enough to meet the draft which the limited number of wells may make upon it, so that whatever interference and loss of head there may be will appear as the wells are drilled and will not seriously increase with the lapse of time.

Wells decrease in flow from several causes, which may be either prevented or remedied. Such are leakage into horizons higher than the water-bearing strata, imperfect or worn-out packings, corroded

casings, clogging of the pores of water-bearing strata, and infilling of the bottom of the bore with débris from above. In the Iowa field the decrease of artesian flows, where such has been noticed, seems to be due largely to one or more of these causes, and at Waterloo they do not form any serious obstacle to an artesian supply.

SUPPLEMENTARY SUPPLIES.

The question of supplementing the artesian supply, if insufficient, is chiefly one of finance and engineering. The cost of bringing in spring water should be considered, and the cost computed also of combining artesian water with that of a filtration plant dealing with water from Cedar River. It may be found that artesian water costs sufficiently less than filtered water to enable it to be economically used as far as it can be obtained without serious interference of the wells. In this case the water from both sources combined would be proportionally less hard than the artesian water alone, and hence a better boiler water, but unless the filtration of the river water were bacteriologically complete the combination would be little less dangerous than the filtered water under the same circumstances.

WATER SUPPLY FROM GLACIAL GRAVELS NEAR AUGUSTA ME.

By George Otis Smith.

INTRODUCTION.

This paper is one of several in the present report which deal with the problems of water supplies of glacial deposits of different types and origins. No other source furnishes so abundant and pure supplies over such large areas as the drift, from which probably considerably over nine-tenths of the wells north of its southern limits obtain their water. The drift is likewise the source of a large proportion of the springs within its area, and furnishes the supplies of the waterworks of many of the smaller cities and towns. At the same time its composition and structure are so complex and variable that it is with great difficulty in many cases that an intelligent understanding of the true conditions can be obtained. It is with the view of presenting examples of the conditions in type deposits that this and other similar papers have been prepared.

The region described in this article was visited in June, 1904, by the writer, at the request of Governor J. F. Hill, chairman of the commissioners of the Augusta, Me., water district. The Silver Lake system of ponds had been considered among the possible sources for a new municipal water supply, and the visit was made in company with Mr. Allen Hazen, consulting engineer.

Spring Brook, which has its source close to these ponds, had been gaged and found to have a discharge insufficient for the demands of the city of Augusta, and the suggestion had been made that this supply could be augmented by water from the ponds in the vicinity. The problem presented at this time, therefore, was the examination of the Silver Lake drainage basin and the determination of the nature of its relation, if any, to the springs which supply Spring Brook.

In presenting the results of this investigation I wish to acknowledge my indebtedness to Mr. Hazen. Although we approached the problem from somewhat different points of view and followed different lines of argument, it was noteworthy that we arrived at

essentially the same conclusions. While the writer had this advantage of discussion of the field observations with a hydrographic engineer, the conclusions here presented are those based principally upon geologic data. Acknowledgments are also due to Mr. W. W. Albee, superintendent of the Augusta water district, for information furnished and for the sketch map accompanying this paper, which is based on the surveys of Mr. Samuel M. Gray, consulting engineer, who also ran the level lines, determining the elevations of the different ponds, as quoted on a following page.

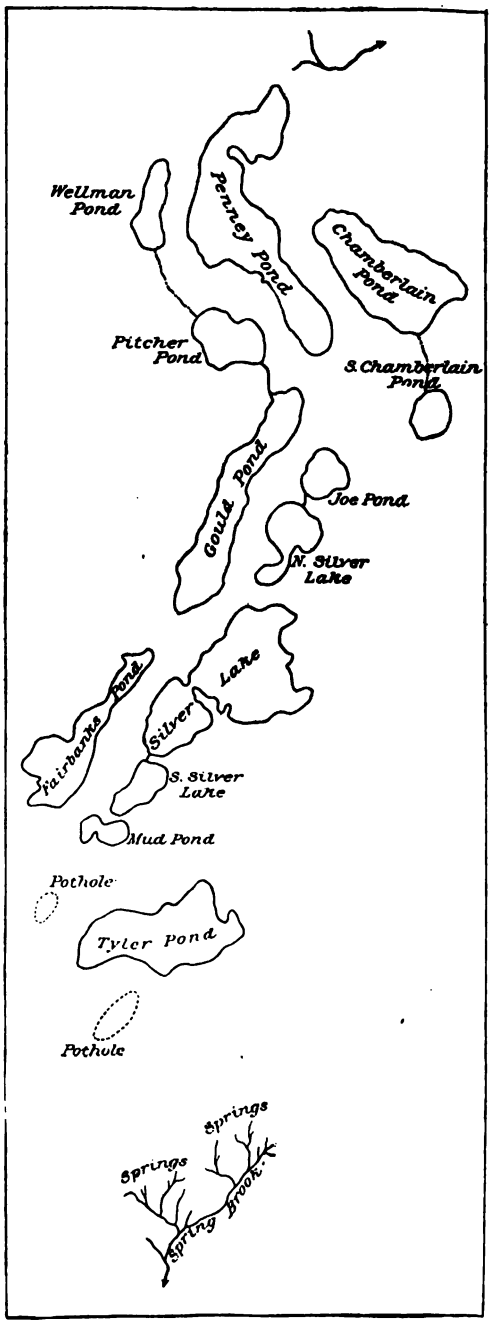

FIG. 35.—Sketch map of lakes near Augusta, Me.

GENERAL DESCRIPTION.

The Silver Lake group of ponds is situated about 5½ miles northwest of the city of Augusta, Me., at the place where the four towns—Augusta, Manchester, Belgrade, and Sidney—come together. Thirteen ponds are included in this system, with an aggregate area of 215 acres, ranging in size from 41 acres to 3, and in depth from 81 to 11 feet. Several of the ponds are connected by sluggish streams, but the system has no visible outlet. A half mile south of Tyler Pond, the southernmost of the group, there are scores of springs, the waters from which unite to form Spring

Brook. This stream enters Bond Brook and thence reaches Kennebec River within the city limits of Augusta.

These ponds are located on a well-defined plateau, which has an elevation of about 300 feet above sea level, Augusta being situated at the head of tide on the Kennebec. This plateau is slightly diversified by a few rounded low hills and ridges, but along its southern border its surface is very level. The "caves," or V-shaped gulches, which have been eroded along the southern margin of the plateau well exhibit the material composing it. Rounded gravels with bowlders up to 1 foot in diameter and fine sand are interstratified, but no clay beds were observed.

The topographic details of this plateau and its composition indicate its features to have been formed by the deposits of a glacial stream. This is, indeed, the southern end of an extensive system of glacial gravels, which has been described by Stone as the Norridgewock-Belgrade system.[a] The basins containing the ponds, as well as the dry kettle holes, doubtless represent ice masses originally inclosed in these glacial gravels.

SILVER LAKE DRAINAGE BASIN.

The area included in this basin is 1¾ square miles. The topographic character of its surface and the sandy soil covering it make the conditions extremely adverse to any loss of rain water by run-off. The boundaries of the basin are not well marked except at the northern and southern ends, where there is a sharp descent into adjacent stream valleys. The drainage basin is subdivided by a winding ridge, which separates two chains of ponds.

The underground character of this basin can be inferred from the exposures of stratified sand and gravel along the southern margin of the plateau. The extent to which this basin is sharply bounded beneath the surface is largely a matter of conjecture. The occurrence of glacial till immediately bordering the plateau on both the east and west suggests that the underground limits of the basin may approximately coincide with the surface boundaries. The fact that ledges of slate also occur both on the east and west borders of the plateau may be regarded as substantiating this opinion.

SHAPE OF THE WATER TABLE.

In a mass of horizontally stratified gravel and sand, with no impervious beds and no marked relief in surface topography, the shape of the water table is important in its bearing upon the questions of underground flow. The factors of impervious strata and surface

[a] Stone, G. H., Glacial gravels of Maine and their associated deposits: Mon. U. S. Geol. Survey, vol. 34, 1899, pp. 181–184.

topography being here eliminated, the form taken by the water table will clearly indicate the direction of flow. Fortunately for this discussion the exact levels of the different ponds in December, 1903, are available. The water levels in these ponds, most of which are without outlets, indicate the position of the water table, or upper surface of the ground water, and these levels are given in the following table. The ridge already referred to separates the group of ponds into two chains, and the elevations for these will be given in separate columns—I being the elevations for the ponds of the eastern chain, and II for those of the western chain.

Elevation of water levels in Silver Lake pond system.

Name.	I.	II.
Chamberlain Pond	268.24	.....
Wellman Pond	.....	266
Penney Pond	.....	265.15
Pitcher Pond	.....	263.05
South Chamberlain Pond	267.90	.....
Joe Pond	267.80	.....
Gould Pond	.....	264.70
North Silver Lake	267.60	.....
Silver Lake	261	.....
South Silver Lake	259	.....
Fairbanks Pond	.....	260.20
Mud Pond	257.30	.....
Tyler Pond	254.30	.....

The table brings out several noteworthy facts. In the first place, with the exception of Penney Pond, in both chains of ponds the elevations of the water surface decrease southward. This indicates a southward slope of the water table. The exception to this generalization is important, since Penney Pond lies at the northern end of the plateau and is separated from the neighboring ponds by a ridge, and, furthermore, has near its northern end one of the few places where a small stream was seen flowing outward from the plateau margin. Just south of Tyler Pond there is a deep kettle hole, which is perfectly dry. Barometric observations, however, explained this apparently anomalous condition by the fact that the bottom of the kettle hole is 5 feet above the water surface of Tyler Pond.

A second feature is the relative independence of the two chains of ponds. It is evident that the ridge separating them is simply the topographic expression of a structural element in this mass of glacial stream deposits. In fact there are also transverse ridges which cause similar variations in level of the water surface of adjacent

ponds in the same chain. Thus Silver Lake is separated from North Silver Lake by a ridge only a few yards across, and the difference in water level is over 6 feet. The slope of the water table apparently varies considerably within this area, but the average slope is not far from 10 feet per mile. The direction of flow is largely controlled by the opportunity afforded for escape along the base of the bluffs forming the southern edge of the plateau, but possibly this flow is facilitated by a slight southern dip of the stream-laid gravels.

The southern slope of the water table over the greater part of this area indicates the direction of underground flow. This in turn at once explains the source of the springs at the head of Spring Brook. The supposition that these springs may be fed from some distant supply, such as Messalonskee Lake, 5 miles north of the springs, is at once controverted. While higher than the springs, this lake is probably 40 feet below the water table of the Silver Lake system, and indeed it is not unlikely that the northernmost pond of the group, Penney Pond, drains partly into a stream flowing northward into Messalonskee Lake.

PRACTICAL CONSIDERATIONS.

It is seen from the above description that the Silver Lake area constitutes a natural system of filter beds. The water falling upon the surface of the plateau slowly percolates through the interbedded sands and gravels. The water issuing from the springs is therefore of exceptional purity, and as regards quality no better water supply could be desired.

Unfortunately the quantity of flow in Spring Brook is insufficient, and one plan proposed was to erect a pumping station upon the plateau and use the pond water as an auxiliary supply. From the foregoing discussion of the conditions controlling the system of ground water in the Silver Lake area, it will be readily seen that such a procedure would be highly inexpedient. The flow of the springs is directly dependent upon the ground water of the plateau, and as it seems probable that there is little flow outward from this basin either to the east or west by reason of the bounding masses of till and rock, it follows that the annual discharge of the springs at the south end of the plateau approximately equals the amount contributed to the basin by the rainfall. The water of the thirteen ponds is merely the visible portion of the supply of ground water in this basin, and to pump from Silver Lake or Tyler Pond would be simply to draw from the same supply as that from which the springs derive their water. While each of these two ponds has a capacity measuring over 200 millions of gallons, yet pumping this water would surely tend to lower the level of the water table, and thus eventually to decrease the rate of discharge at the springs.

WATER SUPPLY FROM THE DELTA TYPE OF SAND PLAIN.

By W. O. Crosby.

TYPES OF GLACIAL DRIFT.

One of the most important sources of water supply in the glaciated regions of this country is the glacial drift. In New England and other regions where the rocks are largely crystalline the drift, in fact, constitutes almost the only source. Of the various types of glacial drift the till or hardpan is the most abundant and widely distributed, and in the aggregate yields large amounts of water. It is, however, the sands and gravels or the coarser parts of the stratified drift which afford the large and important sources of supply. There are many types of these latter deposits, the most common being those of the following list:

1. **Valley or flood-plain deposits of Pleistocene and recent streams.**
2. **Terrace deposits of Pleistocene streams.**
3. **Outwash plains in front of moraines and elsewhere.**
4. **Normal sand plains or delta deposits formed in glacial lakes and other bodies of standing water.**

The last type of deposits is very prominent in New England. Detailed investigations of such a delta have been made at Clinton, Mass., in connection with the building of the Wachusett reservoir of the water-supply system of Boston and the metropolitan district. Many borings were made in this delta, a large number of samples secured, and some sections made—in fact, an unusually thorough knowledge of its structure and composition obtained.

The Clinton sand plain (deposited in the glacial Lake Nashua) is in all respects typical of its class, the essential conditions existing in it being duplicated in many plains throughout New England. The results of the study of its structure and the relations thereto of the ground water are therefore of interest in showing the possibilities and characteristics of water supplies in sand plains in general.

Nashua River holds a unique place among the rivers of New Eng-

land, inasmuch as it is the largest stream east of the Hudson-Lake Champlain Valley that flows throughout the main part of its course in a northerly direction. The deep northward-draining valley of the Nashua presents ideal conditions for the study of the phenomena of glacial lakes, for probably nowhere in New England was this phase of the closing stage of the Pleistocene ice sheet more typically developed.

Although Nashua Valley presents naturally a very attractive field for the student of glacial geology, it was rendered doubly inviting by the operations of the metropolitan water board in the construction of the Wachusett reservoir. This great reservoir, with an area of 6½ square miles and a maximum depth of 129 feet, will be formed by the building of the Wachusett dam across Nashua River and of two auxiliary dams, known, respectively, as the "north dike" and the "south dike," and will reproduce in part the glacial lake which once adorned the upper valley of the Nashua.

The history of the Nashua series of lakes commenced when the retreating margin of the great ice sheet first began to uncover the southern water parting of Quinepoxet River, which unites with the Stillwater near Oakdale to form the Nashua.

During the earliest stage the impounded water of Quinepoxet Valley found an outlet, at an elevation of about 760 feet, across the southern water parting, flowing southward to Blackstone River and Narragansett Bay through the pass now occupied by Chaffin Pond and traversed by the Boston, Barre and Gardner Railroad.

When the ice sheet released its hold on the Malden Hill Ridge at the north limit of the ponded body the water fell to the level of the Boylston stage, finding near Boylston Center an outlet at an elevation of about 440 feet, through which it passed into the valley of Lake Quinsigamond and thence to the Blackstone. The opening of the Boylston outlet involved a change of level of about 300 feet, and such a complete abandonment of the Quinepoxet area that the two parts or stages of the lake nowhere overlap, but appear on the map as entirely distinct and separate bodies of water.

When the ice margin had finally retreated along the eastern water parting to the pass formerly traversed by the Central Massachusetts Railroad, 2 miles south of Clinton (to be closed by the south dike), the level of the lake was lowered about 70 feet, to the Clinton stage (see fig. 36); and its waters probably became tributary to Boston Harbor instead of Narragansett Bay, Concord and Merrimac valleys being still occupied by ice. This is an ideal outlet, narrow and well defined. The minimum elevation of the water parting in the south-dike pass is 365 feet—nearly 370 feet before the construction of the railroad.

THE CLINTON DELTAS.

FORMATION.

With the opening of the south-dike pass came a rapid development of the Clinton Plain, made possible by the necessarily rapid erosion

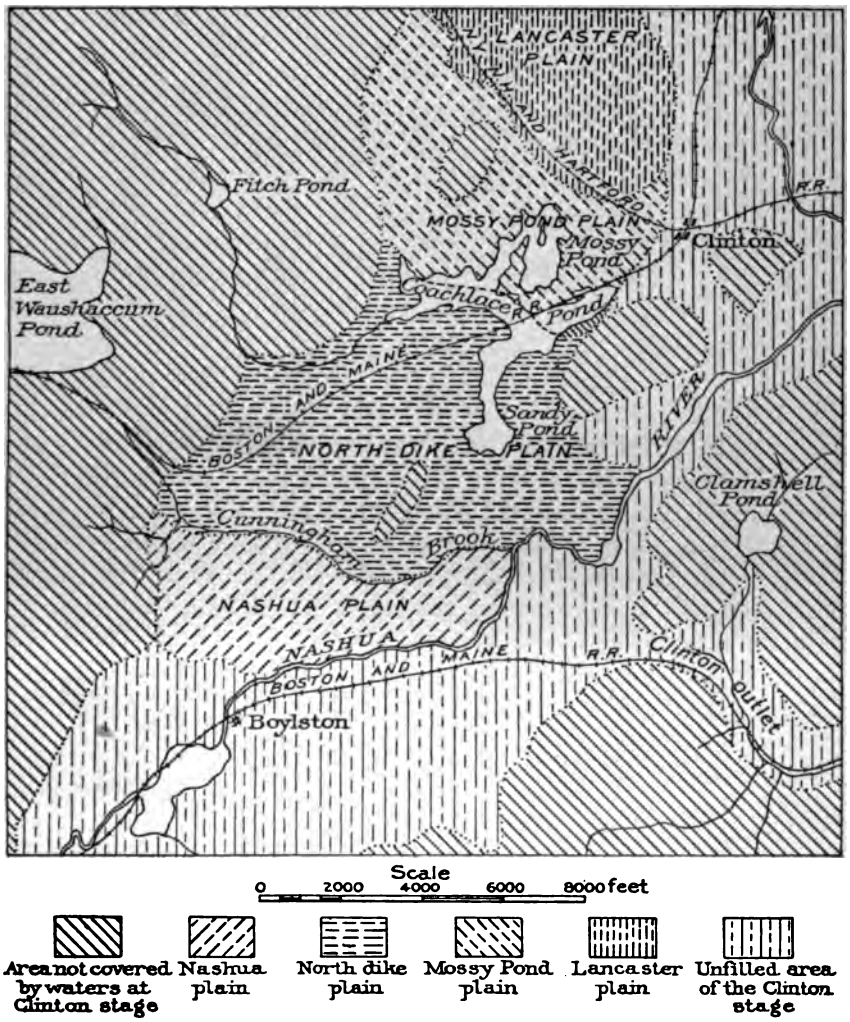

FIG. 36.—Extent of Lake Nashua at Clinton stage and location of the subdivisions of the Clinton plains. The larger portion of the area within the boundary of the lake at the Clinton stage is occupied by sand plains, the Clinton plains proper, the subdivisions of which are represented on the map, lying to the northwest, west, and southwest of Clinton.

of the high and deep deposits of the Boylston stage. In fact, the waste of the Boylston Plain along the axis of the valley in the first few years after it became exposed to the rush of the Nashua and its

tributaries, with a fall of from 10 to 20 feet per mile, must have been enormous; and we can not escape the conclusion that through the cooperation of the Nashua with the glacial streams from the northward the Clinton Plain was developed continuously along the southern margin of the ice to the outlet, the level of which was probably raised somewhat by the extension through it of the coarse topset layers of the delta.

GENERAL CHARACTER.

The delta plains of the Clinton stage, with normal elevations of 375 to 385 feet, are most broadly and typically developed in the districts immediately northwest and southwest of the village of Clinton, or in that part of the valley between South Lancaster and Boylston. They are, in part, indicated with a good degree of accuracy by the contour lines of the topographic map; and those southwest of Clinton are still more clearly and accurately expressed by the contour line of 370 feet on the map of the Wachusett reservoir, this contour tracing the outlines of the plains very closely where they are developed to the normal elevation. The post-Glacial erosive action of the river has left, as a rule, only meager remnants of the Clinton plains up the valley west of Boylston. North of Boylston, however, the valley is much broader, and the ravages of the river relatively much less, so that over an area of several square miles the deltas of the Clinton stage are preserved almost intact. In fact, it may be doubted if anywhere in this region can be found more normal or striking examples of this phase of the modified drift. The deforesting of the area to be covered by the reservoir brings out the various features of the plains in all their pristine distinctness and perfection, so that even in a merely topographic sense a very unusual opportunity is temporarily presented to the student of glacial geology.

Although, as the map shows, the Clinton plains are broadly and typically developed in the districts both immediately northwest and southwest of the village of Clinton, it is in the latter area that they have been most perfectly exposed for study by deforesting, and most fully explored, first, by drilling preparatory to the construction of the north dike, and second, by the excavation of the great trench subsequently filled with impervious material to form the core or cut-off of the dike. The main cut-off trench afforded a nearly continuous section, having an aggregate length of 9,556 feet and a maximum depth of 60 feet, and in addition to this there was a shorter secondary cut-off trench. The wash-drill borings, to the number of 1,131, with an average depth of 83 feet and a maximum depth of nearly 300 feet, are distributed systematically and somewhat uni-

A. KETTLE HOLE IN NORTH DIKE PLAIN, MASSACHUSETTS.

B. VIEW UP THE FOSS VALLEY OF CUNNINGHAM BROOK, MASSACHUSETTS.

formly over an area 9,000 feet in length (east-west) and 2,000 feet in breadth. Nearly 10,000 samples from these borings have been examined, in part somewhat exhaustively, and it is, perhaps, within bounds to say that in certain aspects no similar body of modified drift has been more thoroughly investigated. The available data seem, therefore, to justify a somewhat elaborate presentation and discussion, especially since they throw important light not only upon the structure of these deltas, but also upon the relations of the ground water to this structure; and since they are externally, also, rather impressive examples of the type, presenting ideal developments of all the normal features, including ice contact, frontal and erosion slopes, and the level, upper, or topset surface pitted by kettles.

In a broad way the Clinton deltas are coextensive with the lake at the Clinton stage (fig. 36). They are bordered on the east and west by slopes of rock, or till, and in the southern portion by the higher plains of the Boylston stage. The contact is marked in part by original ice-contact surfaces of the higher plains and in part by erosion slopes cut in these higher plains by the Clinton waters. The principal development of the Clinton plains is west of Nashua River in the region northwest and southwest of Clinton, in which region four successive delta stages are recognized, which, beginning with the earliest, or southernmost, and ending with the latest, or northernmost, are the Nashua, North Dike, Mossy Pond, and Lancaster plains. Their locations are shown in fig. 36. The surface of each of the plains is characterized by numerous kettles, due to the melting of buried or partly buried masses of ice; some of these kettles are of large size and contain ponds (Pl. V, A). The Nashua, North Dike, and Mossy Pond plains all show gentle slopes and faces to the south and east; the first two and the Lancaster Plain have steep ice-contact faces on the north. The Mossy Pond and Lancaster plains merge into each other, and neither the ice contact of the former nor the marginal slopes of the latter are typically developed. The sharp channel of Nashua River, eroded to a depth of 70 or 80 feet through the Nashua Plain, is a characteristic feature (Pl. VI, A).

NORTH DIKE PLAIN.

STRUCTURAL FEATURES.

It is proposed to consider here only that segment of the Clinton Plain crossed by the north dike and bounded on the north by Coachlace Pond and on the south by Cunningham Brook and Nashua River. For, as previously noted, this member alone of the Clinton series has been sufficiently dissected by borings and excavations to afford the data requisite to an understanding of its structure.

General topographic and bed-rock relations.—The North Dike Plain is approximately 2 miles long (east-west) by 1 mile wide in the general direction of its growth from north to south and divided midway of its length by the narrow and overlapping ridges of metamorphic slate or phyllite, on the most southerly of which the Catholic cemetry was formerly located. The western part of the plain is, in most respects, the more normal delta, at least in regard to its formal features—an almost unbroken plain sloping gently and evenly southward from a typical ice-contact margin fringed with kettles to a lobate frontal slope, which is separated from the ice-contact margin of the earlier Nashua plain by the foss valley of Cunningham Brook. In its under surface, also, the western part of the North Dike Plain is relatively simple and normal, since its northern half rests on an approximately plane bed-rock floor (ranging in elevation, as shown by several hundred borings, from about 330 to nearly 370 feet), which also slopes gently southward and is trenched to depths up to 50 feet or more by several southward-sloping and southward-converging rock valleys.

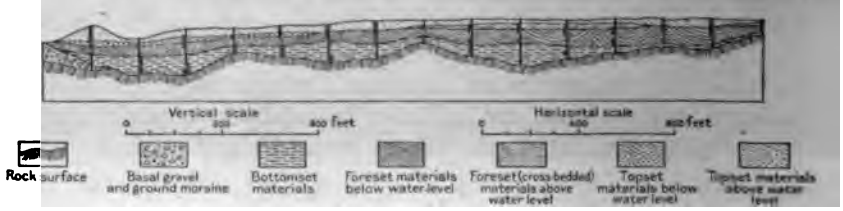

FIG. 37.—Selected east-west profile through a line of borings in westerly portion of north-dike area, Clinton, Mass.

The form of the bed-rock surface, so far as developed by the borings, is shown by the east-west profiles across the valleys (fig. 37).

The eastern half of the plain is far more irregular, both superficially and basally, than is the western half. Midway between the cemetery ridges and Burdette Hill it is widely divided by the kettle basins of Coachlace and Sandy ponds, continued southwestward in a string of more normal kettles; and approximately coincident in position and trend with this depression is the deep, pre-Glacial bed-rock gorge of Nashua River, to which several minor bed-rock valleys with separating ridges of schist are tributary.[a]

The most surprising and puzzling feature of the relations of this plain to the bed-rock contours is the fact that the basin or trough of Coachlace Pond, as it existed before the building of the north dike, although closely parallel to the deep, buried gorge of the Nashua, does not directly overlie it, but is superposed, with 120 to 130 feet of modified drift intervening, upon a distinct bed-rock terrace several hundred feet wide, with an elevation of 190 to 210 feet, separating

[a] Techn. Quar., vol. 12, p. 294.

A. EROSION OF THE NASHUA PLAIN, MASSACHUSETTS.

B. WASH DRILL IN OPERATION ON THE NORTH DIKE PLAIN, MASSACHUSETTS.

the gorge from a well-defined ridge of schist comparable with the cemetery ridges and rising to a maximum elevation of 280 feet, or within 100 feet of the surface of the Clinton Plain. This relation, whether fortuitous or not, clearly demands consideration in any discussion of the origin of the kettles. It appears from the foregoing that the broken eastern half of the North Dike Plain rests upon an unusually rugged bed-rock topography, with a maximum relief of nearly 300 feet and corresponding variation in the depth or thickness of the modified drift; and it may be added that the form of the bed-rock surface is without appreciable influence upon the contours of the delta, except, perhaps, in determining in some degree the location and trend of the north-south line of kettles, or ice-block depressions.

Relations to the ground moraine or till.—With a bed-rock topography of strong relief, the dominant trends of which are obliquely transverse to the direction of glacial movement, it might, perhaps, have been anticipated that the depressions would be deeply filled by the ground moraine. As a matter of fact, however, the borings show that the valleys, and notably the deep pre-Glacial gorge of Nashua River, are remarkably free from till; and this notwithstanding the fact that the North Dike Plain terminates both east and west in prominent drumloids, in which the bed rock is heavily covered with till. Usually the only thing really suggestive of till is a basal layer of gravel of obviously local origin, and ranging from a few inches to several feet in thickness, which many of the borings show resting upon the bed-rock surface. This basal gravel, varying from coarse to fine, but undoubtedly including much coarser material than the wash-drill samples indicate, might perhaps be interpreted as a washed till; but, if so, the washing has been singularly thorough, for the samples show it to be entirely devoid of clay and rock flour, and there is no apparent reason why it should be differentiated in origin from the rest of the modified and water-laid drift. West of the cemetery ridge, however, although the till is restricted to a few thin patches rarely exceeding 5 feet in thickness for the northern profiles, southward down the sloping bed-rock surface it increases somewhat, and in the two or three most southerly profiles it is practically continuous and varies in thickness from 2 to 30 feet.

Collection of boring samples.—The borings in the north-dike area were made with the wash drill (Pl. VI, *B*), which consists essentially of a strong casing pipe approximately 3 inches in diameter, and the drill proper or water pipe about 1¼ inches in diameter, and terminating at the lower end in a cutting edge with two small holes for the escape of water. The casing is driven into the ground by a cast-iron weight which encircles its uppermost length or drivehead, and, falling freely, strikes on a collar firmly attached to the lower end of the

drivehead. In this collar is the outlet for the water, which, escapin from the lower end of the drill, rises in the annular space between th drill and the casing and brings up, if the head of water be sufficien all material loosened by the action of the drill, except pebbles an stones too large for the channel, or exceeding about 1 inch in diame ter. Larger stones are either displaced or broken by the drill o casing. The outflowing stream of turbid water discharges into a tu in which the coarser materials in suspension settle, while the clay an rock flour are largely washed away with the overflow. At convenien intervals, and especially when a change in the character of the dis charge is noted, the water in the tub is poured off, a sample take from the accumulated sediment, and the tub cleaned out preparator to the collection of the next sample. In absorptive strata a part o the water may escape into the ground, reducing the velocity of th excurrent stream sufficiently so that only the finer detritus is brough up; or the water may be wholly lost and no sample obtained until th ground becomes saturated or the casing is driven deep enough to cu off the thirsty stratum. It has been found also that when the casing has reached the great body of fine sand and rock flour, of which th lower part of the deposit is chiefly composed, the drill may be ru down below the casing 100 or even 150 feet, the water rising for thi distance in an uncased well of its own making without collapse o serious caving of the walls. Of course any enlargement of this unprotected part of the hole must diminish the velocity of the water through it, and thus, as in the case of "lost water," tend to prevent coarse sand or gravel from coming up and make the samples more or less incomplete.

The majority of the samples were necessarily taken under the general conditions described above, and these are designated as regular or "incomplete" samples. These were supplemented for certain borings by special or "complete" samples, taken by holding a 2-quart glass jar under the discharge and allowing it to fill but not overflow, and then, after the material in suspension had settled, drawing off the water with a siphon. In cases of persistent turbidity (suspended clay) a few drops of hydrochloric acid were added to the water to curdle the clay and thus secure a more prompt and perfect separation. With these precautions the special samples can not fail to show in due proportion all the materials brought up by the water; but they are still likely to be imperfectly representative of the deposit as it exists in the ground when the detritus is coarse or of a composite (coarse and fine) character, or where any important part of the water is lost. The special samples were taken at regular intervals of 5 feet, and an extra sample whenever a change in the character of the discharge was noted, thus making sure that no important changes were overlooked.

Classification of boring samples.—The special samples, with the regular samples from the same borings, were submitted to elaborate mechanical analyses and filtration tests, to be described later; but the regular samples, as a whole, were far too numerous, as well as too incomplete in character, to justify anything more than a careful macroscopic examination, with a view to an approximate classification in accordance with the following scheme:

Classification of wash-drill samples from site of north dike.

1. Coarse gravel.
2. Fine gravel.
3. Coarse sand.
4. Medium sand.
5. Fine sand.
6. Superfine sand.
7. Rock flour.
8. Superfine rock flour.
9. Clay.
10. Bowlder clay.

The coarser and also the finer grades are, as usual, highly composite or have high uniformity coefficients, while the intermediate grades, especially No. 5, have, for reasons to be discussed later, a high degree of uniformity or relatively low coefficients. The uniformity coefficient is defined as the ratio of that size of grain than which 60 per cent is finer to that size than which 10 per cent is finer, this ratio varying inversely as the actual uniformity. A large number of determinations gave the following as the average or normal maximum sizes of grain in the four grades between medium sand and clay: No. 5, 0.45 millimeter; No. 6, 0.28 millimeter; No. 7, 0.16 millimeter; No. 8, 0.08 millimeter. The averages for the uniformity coefficients for these grades are as follows: No. 5, 1.96; No. 6, 2.11; No. 7, 2.25; No. 8, 1.53. These values of the uniformity coefficients are believed to be essentially normal for grades Nos. 5, 6, and 7, and technically so for grade No. 8. The values for grades Nos. 7 and 8 (2.25 and 1.53) are, in each case, the average of 38 determinations, with minimum and maximum values of 1.49 and 3.30 for grade No. 7 and 1.15 and 1.88 for grade No. 8. But it is very difficult or practically impossible to accurately measure the finer particles of grade No. 8, since they are in their minuteness on the border line of clay; and it is very obvious that where falling below the technical effective size (the size than which 10 per cent is finer), or even where aggregating less than 10 per cent of the whole, they may still be regarded as an important factor in determining the real uniformity as well as in their influence upon porosity and percolation.

General structure.—A normal delta, built by a swift and turbid stream in a body of standing water—that is, formed under the conditions existing in a glacial lake—embraces, as shown in fig. 38, three approximately horizontal beds, which Davis has fitly named the topsets, foresets, and bottomsets. In the topsets, composed mainly of coarse material (gravel and coarse sands, grades Nos. 1, 2, 3),

stranded on the upper surface of the delta, and in the bottomsets, embracing chiefly the finest silt (rock flour and clay, grades Nos. 7, 8, 9) deposited in the standing water beyond the outer margin of the delta and subsequently covered, at least in part, by the continued extension of the latter, the growth is principally in the vertical direction and the lamination horizontal; while in the foresets, formed on the growing edge or frontal slope of the delta and made up almost exclusively of material of intermediate textures (medium and fine sands, grades Nos. 4, 5, 6), the growth is horizontal and the lamination oblique, the laminæ sloping downward in the direction of growth.

The topsets, formed on a surface already aggraded nearly to the base level, are, in spite of their coarseness, of relatively slight aggregate thickness, and they are likely to be much thinner than the combined foresets and bottomsets, this ratio varying directly as the depth of the basin in which the delta is built. It would perhaps appear to

FIG. 38.—Diagrammatic section of a typical delta, showing topsets, foresets, and bottomsets (Gilbert).

many a natural if not a necessary assumption that the bottomsets also should be relatively thin, the foresets appearing thus as the dominant feature of the delta section. The relative thickness of the bottomsets must obviously tend to vary directly as the proportion of silt in the detritus delivered at the head of the delta by the tributary stream and inversely as the area of the basin beyond the frontal slope of the delta; and it is clear that the thickness of the bottomsets should increase from the head of the delta outward because of the increasing time and diminishing area of deposition. Although these principles may require some modification as applied to ordinary deltas, marine and lacustrine, they are believed to be especially applicable to the deltas of glacial lakes of limited area, largely because of their relatively rapid construction and the consequent sharp delimitation of the component features.

The well-determined high proportion of silt (rock flour and clay) in normal drift, averaging more than 50 per cent of the whole,[a] suggests for the limited basins of many glacial lakes an exceptional thickness of the bottomsets, especially toward the lee sides of the basins. The full thickness of the bottomsets is rarely disclosed in

[a] Proc. Boston Soc. Nat. History, vol. 25, pp. 115–140.

actual sections of important deposits;[a] but even this fact added to the foregoing consideration fails to suggest the great depth of the bottomsets indicated by the numerous borings in the north-dike segment of the plain formed in true delta fashion during the Clinton stage of glacial Lake Nashua.

The borings do not, as a rule, reveal the attitude or dip of the lamination, even when adjacent borings are closely compared; and general conclusions as to the relative thickness of foresets and bottomsets must rest largely upon the assumption that grades Nos. 4 and 5 belong especially to the foresets, and grades Nos. 7 and 8 to the bottomsets, and that grade No. 6 holds an intermediate position, marking the transition from the foresets to the bottomsets. These assumptions were sustained by observation wherever, in the course of the engineering operations, the deltas have been sectioned. The most important opportunity for direct observation of the structures below the surface was afforded temporarily during the construction of the north dike by the primary and secondary cut-off trenches, the former extending the entire length of the dike and ranging most of the way from 30 to a maximum of 60 feet in depth. Notwithstanding that the trend of the cut-off is at most points transverse to the direction of delta growth, the walls of the great trench showed in general, below the coarse gravel of the horizontal topsets, southward-sloping layers of medium to superfine sand, rarely more than 10 to 15 feet thick. Since the main purpose of the cut-off is to intercept the relatively pervious topset and foreset beds, it nowhere penetrates deeply the underlying and highly impervious bottomset strata; and hence these have nowhere been exposed for more than a small fraction of their thickness.

The low uniformity coefficient and consequent high porosity of the more characteristic material of the foresets seems to find a ready explanation in the obvious principle that, of the material swept by the distributaries of the glacial stream beyond the outer edge of the delta, only particles of a limited range in size could settle on any narrow zone of the frontal or foreset slope; and yet it is easy to see that the material would tend to become finer toward the bottom of the slope. In the standing water beyond the frontal slope the residuum of detritus in suspension must all settle eventually, with little or no assorting where the process is continuous, the resulting deposit becoming thus highly composite. The importance of this principle in its relations to the storage and movement of the ground water in the sand plains of the glaciated area is obvious.

[a] Investigations of the clays associated with a sand plain at Barrington, R. I., made by J. B. Woodworth (Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 987–988), and M. L. Fuller (Jour. Geol., vol. 7, 1899, pp. 452–462), showed that the bottomset silts may be present in as great or greater bulk than the sands and gravels of the combined foresets and topsets.

The theory of the formation of delta plains in glacial lakes require that the recession of the stagnant margin of the ice sheet should b intermittent or characterized by more or less prolonged halts, with in general, a rather rapid recession from one halting place to th next. The essentially stagnant condition of the ice margin is prove by the rather rare distortion of the delta deposits due to a readvanc of the ice. The glacial streams, superglacial and subglacial, ten constantly to build deltas in the standing water of the lake, but th normal form and structure are fully realized only where the ic margin recedes slowly enough, or halts long enough, to allow th deposit to be built up to the surface of the water. In other words the determining factors are rate of recession, rate of deposition, an depth of water; and, assuming deposition as constant, the formatio of a delta demands, in general, that the rate of recession shall var inversely as the depth of the water, or at least that the rate shall b low when the water is deep, and practically zero for such exceptiona depths of water as obtained in the north-dike area during the Clin ton stage of Lake Nashua. In seeking an explanation of the inter mittent retreat and prolonged halts of the ice margin, we naturall recognize climatic oscillations as probably an important, if not principal, factor. The suggestion is ventured, however, that a stil more potent cause may be found in the accumulation on margina portions of the ice (as now on the peripheral tracts of the Malaspin and Bering glaciers) of englacial drift, which has become superglacia through ablation. Such a covering of drift must retard the melting of the ice, save, perhaps, where the contours of the latter favor th occurrence of standing or stagnant water. The condition here pos tulated appears, also, very favorable to the rapid building of a extended delta against the ice margin, since it affords an abundanc of material in the most advantageous relation, especially if we assum superglacial streams as the chief active agency, as apparently w must with water from 100 to nearly 300 feet deep.

During the recession of the ice margin from the head of one delta to the head of the next delta of the series, the detrital tribute of th stream must be spread over the intervening tract as an imperfectl assorted and stratified, more or less tumultuous deposit of prevailingl coarse material, passing upward somewhat abruptly into the fin silts of the normal bottomsets. Thus we find a ready and adequat explanation of the varying thickness of gravel and coarse sand whic many of the borings show between the bottomsets and the bed rock The only wonder is that this record of a shifting ice margin is no more continuous. The observed facts and the natural tendencie seem, however, to leave us no alternative but to accept these basal accumulations as a normal feature of glacial deltas, a feature, too

which in its relations to the ground water must, notwithstanding its lack of continuity, be somewhat comparable with the foresets.

Effect of ground-water circulation.[a]—In the borings in the North Dike Plain there were encountered at depths ranging from less than 10 to 183 feet numerous layers of iron-stained or cemented sands and gravels from thin laminæ up to beds 55 feet in thickness, the latter probably, however, being composite in character. The materials commonly occur between relatively fine and impervious beds. The material is often of recent deposition, as indicated by the strong ochery color imparted to the water used in drilling, and appears to have been deposited along the course of subterranean drainage by waters passing downward through surface mold and muds and carrying ferrous carbonate derived from the soil and eventually changed to the ferric hydrate. The deposits occur anywhere from the surface to the lower limit of free drainage, but are discontinuous and patchy because the subterranean drainage is located in rather definite courses. They belong largely to the freely draining topset and foreset layers and are seldom represented in the bottomset layers, in which the water is relatively stagnant. Besides the ferruginous material just described there are considerable amounts of drift above the main water table in which a buff tint has been developed by oxidation of the contained iron or of the ferrous carbonate introduced by the ground water. The oxidation is not entirely dependent upon a position above the ground-water level, but is limited to the coarser and more pervious portions of the drift which, remarkable as it may seem, may be oxidized even below the level of the water table, while the firmer portions are often unoxidized even when near the surface.

WATER PROBLEMS.

Relations of the water table.—The North Dike Plain is so completely interrupted by the cemetery ridges as to destroy the continuity of the water table, and in no respect is the contrast of the easterly and westerly portions of the plain more marked than in their relations to the level of the ground water. For the easterly portion this level is, of course, determined by the ponds, and it is interesting to note that before the conditions were disturbed by the construction of the north dike the minor isolated kettle ponds were in substantial agreement as to water level with the Sandy-Coachlace basin. Above this level (about 334 feet) this part of the plain consists chiefly, and at most points wholly, of the foreset and topset beds, and the former especially are in general so highly pervious as to be without appreciable

[a] For complete descriptions of the ferruginous materials, buff and oxidized drift, etc., see Techn. Quar., vol. 17, pp. 64-67.

influence upon the water table, which is continued through them fo long distances without sensible gradient or change of level. Wher however, the bottomsets or sediments of finer textures and high uniformity coefficients than grades Nos. 5 or 6 rise above the pon level the water table promptly rises, attaining a maximum elevatio of at least 365 feet and a maximum gradient of 5 to 6 per cent. W must assume cross bedding of the foresets with alternating, more o less pervious, sloping layers as a general fact, and observation show that in spite of this the water table is a nearly level plane wherever i cuts this middle zone of the delta.

West of the cemetery ridges, where the North Dike Plain has it most continuous and perfect development, the relations of the wate table are distinctly different. Its normal level seems to be 365 to 37 feet, with an extreme range of 360 to 375 feet, and averaging 30 fe higher than the level of the ponds to the north and east. Althoug highest to the north and tending to sink with the plain to the soutl the level is, in the main, remarkably uniform and parallel with th surface at depths of 10 to 20 feet. The ground water is virtuall impounded by high land to the west, the cemetery ridges to the east high bed rock to the north, and the rising and impervious bottomset to the south. The latter barrier especially prevents the water fron escaping freely through the valley of Cunningham Brook to Nashu River. The impounded or almost lake-like condition of the groun water affords but little opportunity to note the influence of the vary ing sediments upon the water level, especially since it is at nearly al points held well above the bottomset beds.

Lost water. We have noted that in porous and absorbent strata especially above the level of the ground water, the water escapin from the drill may be partly or wholly absorbed, and thus fail t return to the surface. This phenomenon, as we should expect, i well-nigh universal in the coarse and pervious topset and forese beds above the level of the ground water. But it also often recurs a various depths down, perhaps, to the bottoms of the deepest boring and it is undoubtedly the most serious difficulty with which the dril men have to contend, and frequently necessitates driving the casin in advance of the drill.

Below the water level the loss of water may be attributed, in man cases, to the simple difference of head, the water standing at higher level in the drill or casing than in the ground, and thu tending to escape into the latter. But, as the boring profiles clearl show, the deeper strata in which the water runs away are usuall interstratified with relatively or practically impervious beds of super fine sand and quartz flour, often of considerable thickness. We ma usually suppose that the water escaping into such intercalated bed

however great the depth, simply causes an equivalent amount to overflow on the water table at the point, however remote, where the bed in question is intersected by that surface. In many cases, however, the avidity and completeness with which the water is absorbed suggest what may be called "thirsty beds"—that is, pervious strata inclosed by impervious material to such an extent as actually or virtually to isolate them from the free-moving ground water above, while in their downward extension they may connect with some body of coarse gravel, possibly pertaining to an earlier ice margin, having more or less free drainage at a lower level, and thus tending to deplete or exhaust the water of tributary beds. This hypothesis has been found requisite to explain some of the hard-packed sands encountered in the north-dike borings;[a] and as an explanation of the "lost water," it possesses the great advantage of not requiring the prompt movement of a long column of water through material in which the friction, added to the inertia of the water, would tend, by loss of head, to minimize the result. In other words, the thirsty sand is right at hand, and not at some remote point perhaps scores or hundreds of feet above the point of escape of the water. This explanation really postulates a localized water table, limited to a single stratum, and far below the normal level of the ground water; but that these conditions do actually obtain we seem to have independent evidence in the "brown" or iron-stained sands to be described later, as well as in the hard-packed sands. The explanation might appear to accord best with the general fact that after a time the lost water returns—that is, ceases to run away. But for this phenomenon we have, perhaps, a simpler explanation in the natural tendency of the escaping water to close the interstices of the sand, and thus prevent its own escape. Again, this explanation is in harmony with the fact that loss of water is unusual below the general drainage level of Nashua Valley north of Clinton (elevation 200 to 250 feet); and the apparent exceptions may, perhaps, best be explained as due to the continued escape of the water through some higher previous stratum where the drill has gone below the casing, or even where it has not, since the water sometimes manifests a strong tendency to work its way up outside the casing.

It appears, then, that "lost water" may require, in different cases, three explanations: First, direct absorption by porous materials above the normal water table; this cause is nearly universal, though not always leading to a total loss, and often operates more or less continuously from the surface of the ground to the level of the ground water. Second, indirect absorption by porous materials above the normal water table, through the medium of intercalated porous strata.

[a] Techn. Quar., vol. 15, pp. 260–264.

influence upon the water table, which is con[illegible] above a local low level long distances without sensible gradient [illegible] free drainage connec- however, the bottomsets or sedim[illegible] uniformity coefficients than gr[illegible] borings along the southern level the water table pro[illegible] ally in the westerly portion, of at least 365 feet and [illegible] ous and normal, and after the must assume cross be[illegible] pervious bottomsets, is a more or less pervious, slopi[illegible] and water rising from a foot or two that in spite of th[illegible] This phenomenon is known by the cuts this middle [illegible] artesian flow attains its maximum

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[illegible] the relations of the springs to the structure of the [illegible] delta are most fully and clearly exhibited in the west- [illegible] the north-south profiles of which show that the springs [illegible] limited to the southern part of the plain; that they occur [illegible] in a thick and continuous series of bottomset strata; and that the elevations at which they occur increase to the southward with [illegible] elevation and depth of the bottomsets. In spite of their [illegible] fine and impervious character, we must suppose that the bottomsets include some relatively pervious beds, which are, natu- [illegible] continuous upward and northward with still more pervious [illegible] beds. Southward these beds must become gradually finer and less pervious and die out as artesian horizons, and thus we find that the lower as well as the upper limits of the springs tend to rise to the southward.

Lost water and springs are terms denoting phenomena of distinctly opposite character, and for their interpretation we have in part assumed corresponding structural conditions, namely, limited pervious beds with free drainage in the case of lost water, and without free drainage in the case of springs. That these conditions actually exist may not be questioned, since they accord perfectly with the natural probabilities of the case, and since the two phenomena rarely

ɔncur even approximately, the springs occurring normally at lower ɜels in any given boring than loss of water, although the latter ɜ now and then recur below the lowest spring, especially with ɜgs of only moderate depth.

ɜen in borings in Coachlace Pond, water was frequently lost at pths of 25 to 100 feet, although the head of the water in the drill above the ground water in the bordering plain must be little or nothing. This seems to prove quite conclusively that the water is absorbed by thirsty or exhausted strata, and does not rise in saturated strata to overflow on the water table.

GENERAL CONCLUSIONS.

The conditions of deposition of a normal delta in a glacial lake determine for the relatively thick series of foreset beds a high degree of uniformity and consequent porosity; and for this series the relatively thin bottomsets form an impervious floor and the still thinner topsets a cover which, by virtue of its coarseness, permits the absorption of the total rainfall and minimizes loss by capillary flow and evaporation, both the composition and structure of the delta favoring extensive storage of water in the foresets.

Probably the most important distinction to be recognized among the deltas of glacial lakes is that based upon areal relation of the delta to the lake. Where this ratio is large, or the delta virtually fills the basin of the lake, as in the Clinton example, the bottomsets are likely to be relatively thick and to limit the development, at least in thickness, of the foresets. On the contrary, if the areal ratio is small, as in the case of a delta of limited area in a relatively large basin, the relation of the foresets to the bottomsets, and of both to the ground water, will be radically different. In the latter case, especially, the topographic relief and distinctness of the delta, where uneroded, attain their maximum development; and the highly pervious foreset and topset beds are then most likely to be free draining, the water table being relatively low and the storage capacity of the delta as a whole at a minimum.

The storage, as noted, must obviously be chiefly in the foreset beds, and these are likely in any case to be protected against loss by the relatively impervious bottomsets, not only downward but laterally as well, in the case of a delta in a basin of relatively limited area. This case is admirably illustrated by the westerly portion of the North Dike Plain, where, through the influence chiefly of the inclosing bottomsets, the water table is held high above the normal drainage level of the district, and the chief loss of water may be assumed to be backward through the abrupt and irregular ice-contact slope.

Third, absorption by intercalated porous strata above a local low lev of the ground water, determined by a relatively free drainage conne tion with a lower part of the valley.

Springs.—A common incident of the borings along the souther margin of the North Dike Plain, especially in the westerly portio where the development is more continuous and normal, and after t drill has penetrated the relatively impervious bottomsets, is a more less vigorous artesian flow, the ground water rising from a foot or tw to 10 or 15 feet above the surface. This phenomenon is known by t drill men as a "spring." The artesian flow attains its maximu height above the surface when the boring is located in a kettle or oth depression, and it never rises above the level of the head or norther edge of the plain. This flow is entirely independent of the head water used in operating the drill. It usually subsides, partly completely, spontaneously within a few minutes, although it ma continue unabated until the water-bearing stratum has been cut o by the casing. As the profiles show, this phenomenon may be repeate once or many times in the course of a deep boring. That the sprin is a true artesian flow is unquestionable, for it is never observed whi the drill is above the normal water table, and only when the borin intersects pervious strata intercalated in impervious sediments, t pervious strata being supposed to be, and in many cases proved to b continuous to the surface.

As indicated, the relations of the springs to the structure of t north-dike delta are most fully and clearly exhibited in the wes erly portion, the north-south profiles of which show that the spring are strictly limited to the southern part of the plain; that they occu only in a thick and continuous series of bottomset strata; and th the elevations at which they occur increase to the southward wit increasing elevation and depth of the bottomsets. In spite of thei generally fine and impervious character, we must suppose that t bottomsets include some relatively pervious beds, which are, natu rally, continuous upward and northward with still more perviou foreset beds. Southward these beds must become gradually finer an less pervious and die out as artesian horizons, and thus we find th the lower as well as the upper limits of the springs tend to rise t the southward.

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Although the foresets must be assumed as subject to considerable variation in texture from layer to layer, it is probable that in any normal example they are throughout so readily permeable as to exert little influence through their structural relations upon the level or movement of the ground water, which simply fills them as it might an ordinary reservoir.

It must be noted, however, that, as the north-south profiles of the North Dike Plain clearly show, the foresets, in consequence of the diminishing power of the distributaries of the glacial stream, tend to become finer away from the head of the delta in the various directions of its growth. This fact, as well as the greater abruptness of the north or head slope, indicates, in spite of the southward-sloping structure planes, the chief loss of water of a free or uninclosed delta in the former direction. The most obvious exceptional cases would be where the delta heads against slopes of rock or till, or is closely joined by the bottomsets and foresets of the next later delta of the series.

Downward, the foresets must blend irregularly with the bottomsets, certain beds apparently retaining the relatively coarse and pervious character for a considerable distance after assuming the approximately horizontal attitude of the bottomsets. Thus are established the conditions favoring artesian flows and "springs," or favoring "lost water," hard-packed sand, and ferruginous layers if the interbedded pervious layers persist and find an outlet at a lower level.

The movement and storage of the ground water may, therefore, be regarded as highly differential and complex in the basal and frontal portions of a delta, while relatively uniform and simple in the topsets and the main body of the foresets.

WATERS OF A GRAVEL-FILLED VALLEY NEAR TULLY, N. Y.

By George B. Hollister.

INTRODUCTION.

General statement.—The valley whose waters are considered in the present paper is located a short distance northwest of Tully, in Onondaga County. On both sides the walls rise to heights of from 1,500 to 1,900 feet, or from 800 to 1,200 or more feet above the rock bottom, which in the vicinity of Tully is buried beneath 500 feet or more of gravels deposited in front of a glacial tongue when its front rested about 2 miles northwest of that town (fig. 39). The portion of the valley occupied by the ice is the relatively unfilled part north of the point indicated, lying mainly below the 900-foot level. The steep, northward-facing, irregular gravels represent the position of the ice front, while the relatively flat plain sloping to the south is built up of sands and gravels deposited by streams leading out from the ice margin.

In view of the fact that the conditions are similar to those in many other valleys in New York and elsewhere in the glacial region, and can, therefore, be considered as representative of a type, it has been thought desirable to present in this report the results of a somewhat detailed study of the quantity and quality of the water supplies in its deposits.

DESCRIPTION OF THE DEPOSITS.

The general character of the deposits has already been indicated. The southward-sloping plain extends southward through the Tioughnioga Valley to Cortland and beyond, being characterized in the vicinity of Tully by a subdued morainal surface with depressions occupied by ten or twelve lakes of sizes varying from a few feet to a mile or more in length. Some of them, notably Crooked and Song lakes, have no visible outlets.

Sections in ravines and gravel pits in the northward-facing escarpment show the material to be composed of gravels, sands, and clays. In a gravel pit on the road leading northward out of the slope on its westward edge at about the 1,160-foot contour, the gravels are rudely stratified and show a decidedly northerly dip. At about the level of the 1,140-foot contour is found a deposit of finely laminated blue clay which outcrops on both the eastward and westward ends of the fill at this elevation and appears to be continuous across its entire face. Above the clay are thin bog deposits with layers of gravel 2 or 3 inches thick and above the latter a bed of calcareous tufa from 8 to 15 feet thick. The clay is practically impervious and limits, at least to a large extent, the downward percolation of water through the gravels.

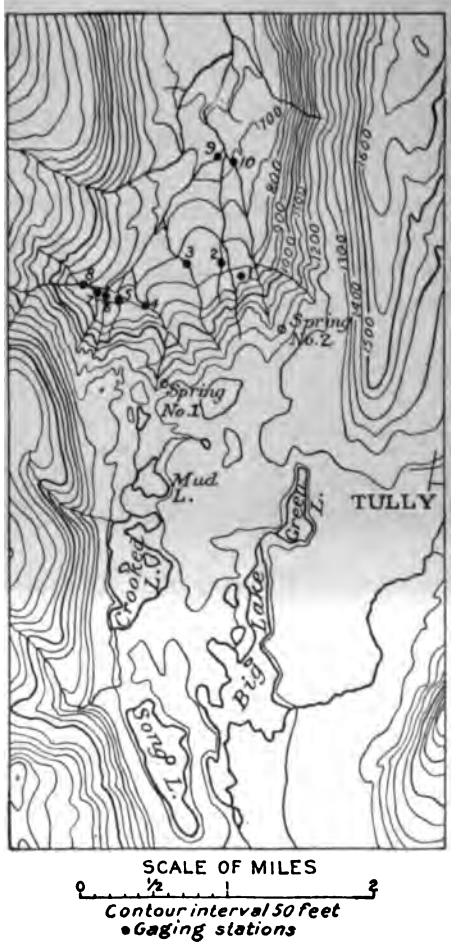

FIG. 39.—Sketch map of vicinity of Tully, N. Y.

WATER SUPPLIES.

SPRINGS.

Discharge.—A large number of copious springs issue from the northward-facing escarpment immediately above the belt of blue clay, occurring at intervals all the way across the valley. Ten of the streams formed by the springs were measured at short distances below their sources on November 7, 1904, by Mr. John C. Hoyt, of the United States Geological Survey, to ascertain the approximate total seepage from the glacial material northward. The locations of the measuring points are noted on fig. 39, and the discharge of the various streams and springs was as follows:

Discharge of spring-fed streams near Tully, N. Y.

	Second-feet.
No. 1	0.26
No. 2	.64
No. 3	.18
No. 4	1.33
No. 5	.09
No. 6	1.05
No. 7	.68
No. 10	1.23
Aside from the above surface flow, spring No. 1 delivers, through a 2-inch pipe, approximately	.75
Spring No. 2 delivers, through a 4-inch pipe, approximately	1.25
Total	7.46

Chemical character.—The relatively large amount of calcareous tufa which was observed on the northward-facing escarpment called attention to the highly impregnated character of the water of the Tully Springs and made it desirable to investigate this feature more fully. Not only was the deposit of tufa found, but calcareous deposits were also observed wherever water from spring No. 1 had splashed on the ground near a large metal kettle at the roadside, into which its water is conducted through a pipe.

LAKES.

Description.—The lakes of the area naturally divide themselves into two distinct series. Song, Crooked, and Mud lakes have no visible outlet, but the latter two receive the run-off from the adjacent shale hill on the west; they form the first series. Big and Green lakes form the second series. They have a tributary stream feeding them from the eastern hills and the Tully Valley and discharge into the west branch of Tioughnioga River at the southern end of Big Lake.

Chemical character.—On November 19 and following a series of samples were taken from springs No. 1 and No. 2 and from the various streams heading above the clay deposits referred to above, as well as from the lakes lying in the depressions of the moraine just south of the crest of the escarpment. Big Lake was sampled in rapidly flowing open water at its outlet. Song Lake, which lies without apparent inlet or outlet, was sampled at its northerly and southerly ends. A narrow strip of low marshy land connects it with Crooked Lake and indicates sluggish communication between the two. Another sample was taken at the southern end of Crooked Lake in a small circular basin separating it from the main lake by a narrow bar. A sample was taken from the hillside streams tributary to Crooked Lake, about 250 to 260 feet above its surface, and another

sample at the north end of Crooked Lake at its outlet, a sluggish stream flowing northward into Mud Lake. Mud Lake was also sampled near its outlet into the small body of water still farther north. From the northern and southern ends of Green Lake samples were taken, which, with those secured from the springs and streams flowing down the escarpment, completed the series.

The analysis of the samples, principally for chlorine and alkalinity, reveal conditions of peculiar interest. The samples taken from the series of lakes without surface drainage, viz, Song, Crooked, and Mud, are comparatively low in chlorine and alkalinity as calcium carbonate, except the small and most northern of the series, lying at the crossroads 1½ miles west of Tully Center, whose alkalinity registered 91, between three and four times that of the others. On the other hand, in the second series, Big and Green lakes, the chlorine about doubles and the alkalinity increases to five or six times that of the western chain, being 89 and 115 for the north and south ends of Green Lake and 121 for Big Lake at its outlet. This is the more remarkable when it is remembered that Big and Green lakes drain into the Tioughnioga, while the others are without surface outlets.

Another feature of interest is that the analysis of water from the stream which drains the shale hillside into Crooked Lake shows about the same chlorine and alkalinity as Crooked Lake itself, indicating quite clearly that Song, Crooked, and Mud lakes are fed by surface flow and subsurface seepage from the adjacent shale hills and have an outward flow through the surrounding gravels, which keeps them relatively soft. On the other hand, the much greater hardness of Big and Green lakes, in spite of some surface drainage which they receive, indicates an easy interchange between the waters of those lakes and the ground water or possibly an eastward seepage from Song and Crooked lakes, during which the latter waters take up large quantities of calcium carbonate and sodium chloride from the glacial material.

The seepage waters forming the escarpment spring and streams likewise show a high percentage of chlorine and alkalinity, even higher in some cases than Big and Green lakes, indicating a still greater concentration of salts. Spring No. 1, on the east side of the moraine, had a chlorine content of 5.2 and alkalinity of 89. It is interesting to note that this spring lies about due north from Green Lake and that its waters analyze the same as those of the lake.

Spring No. 2, near the western side of the moraine, showed an alkalinity of 182, a very high percentage, while the streams on the western and central parts of the moraine showed alkalinity of 105 and 160, respectively. It is noteworthy that the alkalinity decreases as the western side of the valley is approached—where the softer seepage waters from the hills are more strongly felt.

Analyses of stream, lake, and spring water near Tully, N. Y.

LAKES DRAINING NORTH; NO SURFACE OUTLET.

Analysis No.	Iron.	Chlorine.[a]	Alkaline.[b]	Sulphates SO_3.	Remarks.
12	Trace.	2	22	0	South end Song Lake.
13	Trace.	2	17	0	North end Song Lake.
14	.....	2	32	Trace.	South end Crooked Lake.
16	Trace.	2.8	22	Trace.	Outlet (north end) Crooked Lake.
17	Trace.	2	30	Trace.	Mud Lake near outlet.
25	Trace.	2	91	Trace.	Pond at crossroads west of Tully Center.

STREAMS AND SPRINGS NEAR TULLY.

15	Trace.	2	23	Trace.	Stream from shale hill west of Crooked Lake.
20	Trace.	5.2	89	Heavy trace.	Spring on eastern part of moraine north of Green Lake.
21	Trace.	4	105	0	Stream on western part of moraine.
22	.....	1.5	160	.....	Stream near center of moraine.
23	0	4	182	Heavy trace.	Spring near center of moraine.
24	0	2.8	160	Trace.	Head of stream (same as No. 22) near center of moraine. Sample taken 150 yards north and 15 feet below No. 25.

LAKES DRAINING SOUTH.

19	Trace.	5.2	89	Heavy trace.	North end of Green Lake.
18	Trace.	6	115	Heavy trace.	Outlet (south end) Green Lake.
11	0	3.5	121	Trace.	Outlet (south end) Big Lake.

[a] In parts per million.

[b] Alkaline carbonates reduced to an equivalent of calcium carbonate. Parts per million.

SUMMARY.

The presence of a large amount of underground water is revealed near Tully, N. Y., by numerous vigorous springs which occur on a northward-facing glacial escarpment, just above a heavy blue-clay deposit, approximately 1,140 feet above tide and about 100 feet below the crest of the morainal plain. These springs feed strongly flowing brooks which unite to form Onondaga Creek. From measurements made with current meter on November 7, 1904, the outflow of

these seepage waters was found to be about 7.46 cubic feet per second, or approximately 4,847,000 gallons in twenty-four hours.

These waters when tested were found to be exceedingly high in alkalinity and chlorine, as was indicated by the occurrence of a thick bed of calcareous tufa from 8 to 15 feet thick just above the clay deposit.

Other evidences of like physical characteristics of the ground waters were also found in the Tully lakes which lie just south of the escarpment edge in a well-developed kettle moraine. Here Song, Crooked, and Mud lakes, which border the hills on the western side of the valley, though without surface outlet, are kept comparatively soft by the surface and seepage inflow of soft water from the hillside, while Big and Green lakes, which lie in the center of the valley well surrounded with glacial material, have relatively high alkalinity and chlorine, though they drain into the Tioughnioga River with swift discharge.

The marked difference in character of water in these two sets of lakes seems to point to the probability that subsurface water passes eastward from the Song and Crooked lakes series, through the glacial gravels, and, after becoming highly impregnated with calcium carbonate and sodium chloride by contact with the glaciated material, appears in the easterly—or Big and Green lakes—series greatly altered. The subsurface waters in this region in general, from whatever source, take up large quantities of the salts found in the glacial débris and appear highly charged with them in the various lakes and springs.

NOTES ON CERTAIN HOT SPRINGS OF THE SOUTHERN UNITED STATES.

By Walter Harvey Weed.

INTRODUCTION.

The importance and economic value of the natural hot waters of the United States as a factor of our national wealth is much greater than is generally realized. In some instances the waters are utilized on a large scale for heating, and in others they are bottled for shipment as table waters or are valuable as a source of carbonic-acid gas. In the majority of cases, however, the money spent by visitors, either sick or well, attracted solely because of the hot waters, forms a perennial source of wealth to the local community. The amount of money thus annually expended is very large, far larger, indeed, than is generally conceived, but in our own country it is difficult to estimate closely the amount. It has been stated in Germany that the money brought into the country and spent at Carlsbad and the lesser spas exceeds in amount the total value of the mineral production of the Empire. The waters of this country are as varied and as valuable as those of Germany and when accompanied by the diverse attractions seen at the various springs of France and Prussia will probably be as popular, though as yet the appreciation of the pleasure and health-giving results accruing from a visit to any of them is not general.

OCCURRENCE OF SPRINGS.

DISTRIBUTION.

The distribution of hot springs in the United States coincides very closely with that of the mountain uplifts. They are found in the Appalachian region of the Atlantic border, but are lacking in the Mississippi Valley and Great Plains regions except where the mountain uplifts—that of the Ozarks at Hot Springs, Ark., and the Black Hills at Hot Springs, S. Dak.—rise above the general level. In the Rocky Mountains, Great Basin, and Pacific coast regions hot and even boiling springs are very common, especially in connection with areas

of recent volcanic action. Though the Western States contain great numbers of thermal springs, only the most prominent ones are generally known, and information about even these is confined to a statement of the temperature, sometimes accompanied by an analysis of the water, made in a commercial laboratory. Such geologic notes as have been made upon these western springs will be presented in a paper to be published later.

GEOLOGIC RELATIONS.

The thermal waters of the Atlantic border States are none of them of very high temperature, but they are widely known for their medicinal value, and practically all of them are utilized for health and pleasure resorts. The Virginian springs are the best known and longest studied. According to W. B. Rogers, whose classic researches on Virginia geology laid the foundation for our present knowledge of the region, the springs are confined to the Appalachian province, where the warm waters usually outflow from the western side of long anticlinal folds, especially the greater and overturned arches, whose erosion exposes the oldest rocks. There is as yet no reason to doubt the explanation offered by this geologist that the springs owe their heat to the normal downward increase of temperature of the earth's crust, surface waters having penetrated to considerable depth and ascended long faults and slip planes of the folded strata. There is, however, a lamentable lack of exact data concerning any of the Appalachian springs. Statements are freely made that the temperature does not vary and that the discharge is constant from season to season, but as no systematic records of temperature or of discharge appear to have been made, the accuracy of such statements may well be questioned, especially as it is well known now that in European springs formerly considered constant marked changes occur, not only from year to year, but from season to season. The highest temperature of any of the waters of the Appalachian region is that of the Boiler Spring, at the Hot Springs of Virginia, which is stated to be 106°. More commonly the springs of this region do not exceed 90°. At the hot springs of North Carolina, situated on the western side of the mountain region, the geologic conditions have been carefully investigated by Keith,[a] though without reference to the hot springs. The temperature of the water is here as high as 104°, and the spring comes up along a fault plane, affording a quick exit for waters which have seeped down through permeable sandstones to considerable depths, the throw of the fault being about 6,000 feet.

[a] Keith, Arthur, Description of Asheville, N. C., district: Geologic Atlas U. S., folio 116, U. S. Geol. Survey, 1904.

WARM SPRINGS OF GEORGIA.

The only thermal waters of the Southern Atlantic States known to exist, outside of the Appalachian region, are those of Warm Springs, Meriwether County, Ga. As information on these springs is scanty, and as the location, favorable climatic conditions, character of water, etc., all indicate their development into a great winter resort, some detailed notes are given herewith.

Location.—The Warm Springs of Georgia are situated about 85 miles south-southwest of Atlanta, along the branch line of the Southern Railroad running from that city to Columbus. The place is in the Piedmont Plain, whose gently undulatory surface runs eastward to the coast and southward to the lowlands of Florida. A long, low, wooded ridge, called Pine Mountain, rises above the plateau and forms the most conspicuous feature of this part of the State. As the region is unmapped the extent and relations of this ridge, said to be nearly 70 miles long, are as yet undetermined.

Geology.—The hot waters issue from the north base of a spur of Pine Mountain. The region surrounding Pine Mountain is underlain by micaceous schists with a general northeast-southwest foliation and steep dip. A few miles north of the springs these rocks are cut by an intrusive mass of granite, a prong of the great granite mass of central Georgia.[a] The schists are deeply weathered and mantled by red clays, but stream courses and railway and road cuttings afford exposures showing the nature and structure of these earlier rocks.

Pine Mountain is formed of sandstones and sandy shales. The summit is strewn with blocks of gray sandstone: the gulches show alternating beds of laminated sandstones and shales, often friable and loosely cemented. The general strike of these beds is with the ridge or mountain and the curving strike and steep dips near the springs (28°) show an anticlinal folding, the hot waters issuing from along a fracture at the base of an offshoot or spur of the main mountain mass. This fracture line coincides with a bed of well-indurated quartzite, and its course is marked by several small outflows of warm water besides the great springs supplying the bathing establishment. That faulting occurs is shown by the polished and striated surfaces on the quartzite ledges along the base of the slope, and it is noteworthy that these features are less marked and disappear a short distance away from the springs. This quartzite is underlain by more friable beds exposed along the roadside to the hotel and covered by similar rocks seen to the east.

The structural conditions indicate an ascent of the head water along an open channel in a great fracture. There is no doubt that if ordi-

[a] Watson, T. L., Granite and granite gneisses of Georgia: Bull. 9 A, Geol. Survey Georgia, 1904.

nary ground waters penetrate slowly to a sufficient depth they will be heated by the normal increase in temperature of the earth, a feature encountered in all mining operations. With sufficient head and an open conduit, permitting rapid ascent, they will rise to the surface and issue as hot springs. The Georgia springs, therefore, present no unusual features, save their occurrence outside of the area of Appalachian folding and their remoteness from recent igneous intrusions. Assuming a mean temperature of 60° F. at the locality, and a heat increment of 1° F. for each 60 feet of depth, the temperature indicates an ascent from a depth of about 1,600 feet below the present surface, a very moderate depth.

Composition.—An examination of the hot waters made on December 1, 1904, showed a temperature of 87° F. and a faintly alkaline reaction. Sulphuretted hydrogen was tested for but not found. There was not enough carbon dioxide present to be noticeable, the water being limpid and tasteless, but not flat.

No analysis has been made of the water by the Survey, but in the following table the result of an analysis made for and published by the owner is compared with an analysis of the water of Hot Springs, Ark. As will be seen the waters are almost identical, but the Arkansas water is hotter (temperature 146° F.) and deposits carbonate of lime about the outlet; the Warm Springs water forms no deposit and no old hot-spring deposits occur.

Analyses of waters of the Warm Springs of Georgia and Hot Springs of Arkansas.

[Grains per United States gallon.]

Solids, dissolved.	I.	II.
Carbonate of lime	6.099	7.14
Carbonate of magnesia	.097	1.03
Carbonate of iron	.087	.06
Sulphate of lime	.553	-------
Sulphate of soda	.862	.42
Sulphate of potash	.246	.19
Chloride of sodium	.011	.24
Alumina	.462	Trace.
Silica	1.410	2.59
Organic matter and combined water	.865	-------
Iodine	Trace.	Trace.
Bromide	Trace.	Trace.
Total solids dissolved	12.512	11.74

Analysis I.—Water of Warm Springs, Georgia, analyzed by H. C. White, State chemist.
Analysis II.—Water of Old Hale Spring, Hot Springs of Arkansas, State Geological Survey.

Discharge.—The discharge of the Warm Springs has been accurately determined by the engineers of the United States Geological Survey and found to be 1,892 gallons per minute.

HOT SPRINGS OF ARKANSAS.

REGION OF THE HOT SPRINGS.

CHARACTER AND LOCATION.

The most famous and most frequented health resort of the United States is probably Hot Springs, Ark., a city of about 12,000 permanent inhabitants that has grown up about the hot springs of the place, and exists wholly upon the money spent by the visitors to these springs. Originally a resort only for the sick and suffering, it has grown to be a great pleasure resort, and is practically the only one of the American resorts that is comparable with the great European spas in the attractions and diversions offered to visitors. The hot springs themselves and the mountains near by are the property of the United States Government, a fact not, perhaps, generally known. As a result the hot waters are carefully guarded against pollution, and equitably distributed to bath houses, whose luxurious appointments exceed those to be found anywhere else in the United States.

The Hot Springs of Arkansas are situated in the geographic center of the State, 50 miles distant from Little Rock, and about 75 miles east of the Indian Territory line. The locality is accessible by the Iron Mountain Railway and the Choctaw route, both of which run through cars from the large cities of the country. The location is 600 feet above sea level and lies at the easterly base of the mountain complex known as the "Ouachita Range," the near-by peaks of which are often called the "Ozark Range," although that name really applies to the mountains in the northern part of Arkansas and the southern part of Missouri.

HISTORY AND MANAGEMENT OF HOT SPRINGS REGION.

The Arkansas Hot Springs have been known since the early settlement of Louisiana. Although it is only a legend that they were visited by De Soto on his trip to the Mississippi, there is no doubt that they were used by the Indians before the advent of Columbus, as abundant evidence was found in early days that the Indians quarried the dense rocks near the springs for arrowheads and spearheads and utilized the waters for bathing.

In 1804 two members of the Lewis and Clark exploring expedition visited the place and found that white visitors had already used the

waters for bathing. In 1818 the lands on which the springs are located were ceded to the General Government by the Quapaw Indians and became afterwards a part of the Territory of Arkansas. The ground about the springs was located by various claimants before the organization of the Territory of Arkansas, but by act of Congress the springs and the ground about them were reserved in 1834 for the United States Government, thus making the first national-park reservation in the country. Owing to the claims made by various parties to a private ownership of the springs, they remained in the possession of the claimants until the United States Supreme Court decided in favor of the Government in 1877.

Under acts of Congress the mountains adjacent to the springs are permanently reserved for parks, the hot waters are piped to various bath houses, and the supply is under the control of a superintendent of the Hot Springs Reservation, appointed by the Secretary of the Interior. The regulations now prescribed by that Department provide for a rental of land used by various individuals and for the payment of $30 per year for each tub used by bathing establishments. The income is used for the payment of administrative expenses, for the maintenance of a free bath house, for building roads and pathways on the mountains back of the springs and the adjacent mountains, and for gardening. The receipts amount to about $18,000 per year. The superintendent is charged, under supervision of the Secretary of the Interior, with the care of the entire reservation as well as its protection and improvement. It is therefore policed and improved by the Department. The results achieved by this wise system speak for themselves in the beautiful driveways, picturesque walks, and fine flower beds, which add their charm to the natural beauty of the place.

TOPOGRAPHY OF HOT SPRINGS REGION.

Central Arkansas consists of a low-lying, nearly level eastern portion and a hilly or mountainous western region. The first region extends from Mississippi River westward to Little Rock, Benton, and Malvern. The hilly country of the Ouachita Mountain system begins just west of the Iron Mountain Railway, where it has a width of 36 miles, and extends westward, gradually narrowing as it approaches Indian Territory. The eastern level country is part of the Tertiary Mississippi Valley region. The western hilly country consists of a central complex of hills, flanked by sharp spurs and ridges, which extend outward into a much lower country of slight relief. This hilly country is dignified by the name of the "Ouachita Mountain system," the ridges rising gradually in elevation westward.

Near the Indian Territory line the general level of the intermontane plain is 1,000 feet above tide and the crests of some of the ridges attain elevations above 2,500 feet. Near Hot Springs the mountain area seldom attains an elevation of more than 1,200 feet above the sea, or 600 feet above the surrounding country; yet, when seen from the lower country about it, the hills rise so abruptly that they appear to deserve their designation. The mountains near the Hot Springs are particularly impressive, and the local summits have received special designations, as "West Mountain," "Indian Mountain," etc. These mountains have been grouped together by some writers under the name of the "Ozark system," but they have been more fittingly christened the "Zigzag" Range by Professor Branner, of the Arkansas Geological Survey. This range has an extreme length of 25 miles and a width of 6 to 8 miles. The general trend of the ridges is almost at right angles to the system. These ridges are narrow and sharp, with a height of 500 to 600 feet, and they are particularly numerous in the vicinity of the Hot Springs.

The Hot Springs are situated in a valley between two wooded, rocky ridges known as "West Mountain" and "Hot Springs Mountain." The water issues from vents in the old, gray, hot-spring deposit, or tufa, that covers the basal slopes of Hot Springs Mountain east of Hot Springs Creek. This location is on the outer border of the mountain system. To the east the country falls away gently to Ouachita River, and the city of Hot Springs has been built partly in the ravine and the intermontane basin to the north and partly in the eroded plateau lying south of the springs and outside of the mountain area. The mountain slopes are rocky, and are often ribbed with abrupt cliffs and rugged ledges with extensive slopes of talus. They are generally thickly mantled with a heavy forest growth of oak, pine, chestnut, and other common forest trees, and they support a more or less abundant undergrowth. The ravines are generally narrow and the streams swift running, but good exposures of the underlying rocks are seldom seen, owing to the thick forests that cover the slopes. There is an evident relation between the hard rocks and the hills and between the softer rocks and the valleys, although the streams do not accord with any definite geologic structure, but flow in synclines, in eroded anticlines, and across the strike of the beds as well. Several gaps indicate old and now abandoned stream courses and show a prolonged period of adjustment, in which the streams shifted several times before reaching their present position. Although the springs are on the borders of these mountains, this location is not wholly outside of the mountain area, since the Trapp Mountain Range lies south of Ouachita River, so that the springs are on the north side of a synclinal basin

that forms an embayment between the main Ouachita system and a small east-west spur on the south. The region is well watered and well drained. In the immediate vicinity of Hot Springs, Hot

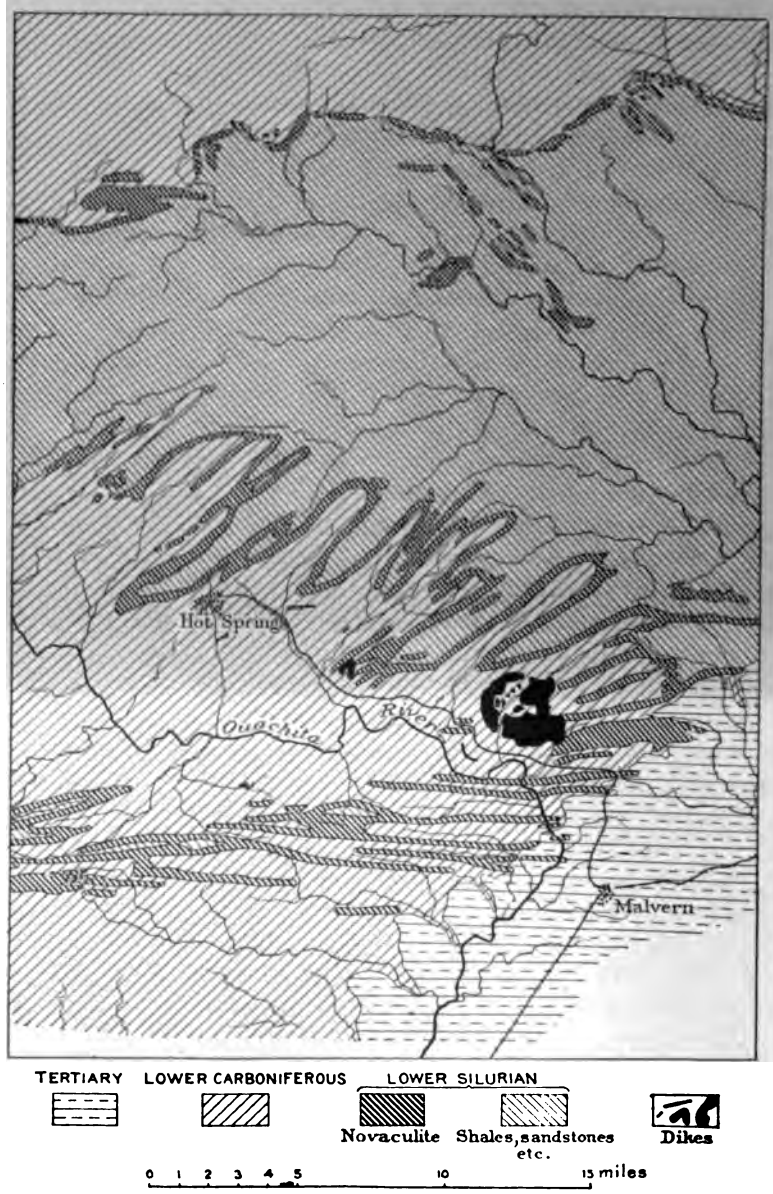

FIG. 40.—Geologic map of Hot Springs, Ark., and vicinity.

Springs Creek and Gulpha Creek, both of which flow into Ouachita River, drain the entire region, the former stream flowing due south and reaching the river 4 miles below the city.

The lower country near the springs, upon which a considerable part of the city is built, is a dissected plain in which broad plateau levels alternate with shallow drainage courses that are tributary to Hot Springs Creek.

The climate of the region is a mild one, lacking both the extreme heat of summer and the cold of winter. In the summer months the air is tempered by the breezes from the mountains, and in winter the average temperature is very slightly below that which prevails at New Orleans and other southern cities. Flowers and shrubs of semitropical character grow in the open air, but the occasional frosts of winter are so sharp that a strictly semitropical vegetation will not exist.

GEOLOGY OF HOT SPRINGS REGION.

Character.—The rocks seen about Hot Springs are chiefly of sedimentary origin and were formed beneath the waters of a Paleozoic sea. They occur in well-defined formations, which were folded when the mountains of the region were formed by the compressive stresses of earth movements, and subsequently eroded by ordinary atmospheric agencies. These rocks are cut by a few narrow, insignificant dikes of igneous rock, which are supposedly connected with the large masses of granite and other igneous rocks now seen at Magnet Cove and Potash Sulphur Springs. In addition to the rocks mentioned there is a considerable area of dark-gray and porous travertine, or calcareous tufa, formed by the Hot Springs.

The sedimentary rocks seen in the vicinity of the Hot Springs consist of shales, sandstones, a few beds of impure limestone, and the rock called novaculite. This last-named rock, of which the well-known Arkansas whetstones are made, is the most conspicuous and important rock in the locality. It is the typical rock of central Arkansas, and, though found over a large area, the material pure enough to be used for whetstones is confined to the vicinity of the Hot Springs. It is this rock that has, by reason of its hardness and its resistance to erosion, made the mountains about the springs, and it forms the cliffs and prominent ledges seen in the district. The bedded rocks form a series, shown in the following table, in which the youngest beds are placed at the top of the column and the oldest strata at the bottom.

Section at Hot Springs, Ark.

Geological age.	Thickness in feet.	Character of rock.
Carboniferous.	200	Shales: gray or black graphitic shales with fragments of plant remains, red and yellow colored when altered.
		Sandstone, impure and clayey, with softer layers alternating with softer material.
	250	Quartzose sandstones, passing at times into conglomerates and well exposed along the basal slopes of Hot Springs Mountain.
Lower Silurian.	12	Novaculite breccia.
	5	Impure novaculite, with iron and manganese.
	100	Novaculite in thick and thin beds, with some layers of siliceous shales.
	75	Sandstone passing into novaculite.
	38	Shale, siliceous, and passing into novaculite.
	200	Massive novaculite, from which whetstone is taken.
	230	Shale, siliceous, with thin layers of novaculite.
	200	Impure novaculite.
		Shales, red and green and gray, with siliceous layers.
		Shales, black, and carrying fossil remains (graptolites).
		Limestone, thinly bedded, blue, and generally argillaceous.
	200	Sandstones.

Structure.—Near Hot Springs the rocks have been compressed into great folds which now form the mountains, and this compression is so great that the folds have been overturned, and in the gorge of Hot Springs Creek the section now exposed shows the younger beds resting beneath the older ones. In addition to this there has been some faulting in Indian Mountain, by which an overthrust has pushed up the older beds over younger ones. For this reason the section (fig. 41) is not always easily made out, but it can be seen in the slopes of West Mountain, although, as will be noted there, the younger beds lie below the older and the rocks have a dip of from 25° to 70°.

Fig. 42 shows a cross section through the low southern end of Hot Springs Mountain and up the valley along Main street. The rocks are well exposed along the line of this section, especially in the quarries and cliffs where the street excavations expose the rocks forming the steep, narrow mountain ridges.

The succession of beds exposed at this place has a steep dip northward, the inclination varying from 25° at the south end to 45° at the north end; all the beds are overthrown, the oldest being on top,

as seen in the cliffs. The novaculites are the most conspicuous rocks; their creamy-white color, dense, even grain, remarkable hardness, and thin bedding are well seen in the beds of the section. The underlying graptolitic shales are also exposed, but the intervening shaly beds are hidden. The upper bed of novaculite passes upward into a

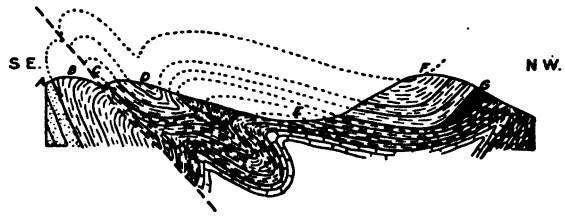

FIG. 41.—Geologic section near Hot Springs, Ark. *A*, Overlying sandstone; *B*, novaculites of Indian Mountain; *C*, fault line; *D*, faulted novaculites of Indian Mountain; *E*, graptolite shales; *F*, novaculites of North Mountain; *G*, brown and red shales.

bed of breccia 12 feet thick, which adjoins the beds of younger massive and coarse sandstone, aggregating about 200 feet in thickness. These are the rocks seen about the hot-springs vents. They grade into softer argillaceous sandstones, which, in turn, pass into varicolored soft shales usually having bright reddish or yellow tints, often graphitic.

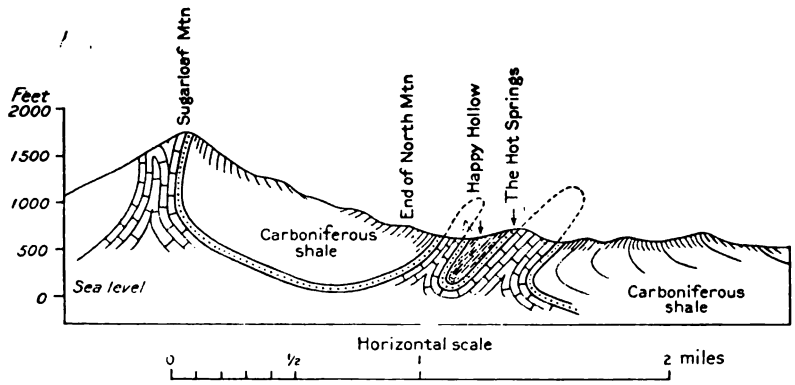

FIG. 42.—Geologic section through end of Hot Springs Mountain and the city of Hot Springs, Ark. Structure shown by novaculite (whetstone) beds and sandstones above them.

The Carboniferous shales, which are the youngest rocks of the district, are well exposed on Malvern avenue near the Park Hotel, where olive-colored sandy shales have been found to contain plant stems and fragments of fern fronds. The shales are rarely indurated enough to form slates, though a few quarries have been opened in them and slate of a poor quality extracted. Where the shales are slightly altered they are sometimes valuable for brick and terra-cotta burning, though most of the clay used for that purpose is derived from the disintegrated material washed into the creek bottoms.

The sandstones are of variable texture and composition. The coarser-grained rocks are nearly pure quartzose sand, but the intermediate beds are quite clayey. The chief sandstone horizon seen at the springs is the one lying just above the novaculites, and this rock is the one which is so prominent on Hot Springs Mountain and West Mountain.

The novaculites are the most interesting rocks of the region. They consist of nearly pure silica, containing less than one-half of 1 per cent of other material. The rock is very dense, homogeneous, of a cream or white color, and fine grained, resembling in appearance the finest Carrara marble. These rocks are used for whetstones, the finer-grained form being called Arkansas stone and the coarser-grained rock the Ouachita stone. This material has a marked conchoidal fracture and resembles chert in its general appearance, although, as will be shown later, this appearance is purely a superficial one, and the material differs markedly from chert in its origin and composition. Although brittle and lacking the toughness of chert, it was extensively used by the Indians, who quarried it by building fires upon the outcrops until the stones were heated and then quenched the fire with water, thus chilling the rock and causing it to split and spall into fragments which were easily removed. In this condition it was readily chipped by the use of round stone hammers, great quantities of which have been found by the early settlers and some of which have been seen by the writer at some of the more remote quarries. The rock is finely jointed, and in quarry faces this jointing is more conspicuous than the bedding planes. These phenomena may be well observed in almost any of the excavations along Main street, above the Government reservation. The finer-grained material seldom forms good outcrops, because of this jointing and also because the rock contains a small amount of water, which, when frozen during the frosts of winter, shatters the stone and covers the outcrop with fine débris. This débris is extensively used as a road material, and wherever applied forms a most excellent surface.

The novaculite formation is from 500 to 600 feet in thickness; this measurement including some flinty shales, some soft shales, and some sandstones. The novaculites proper are prominent members of the formation, occurring in beds from a few inches up to 12 or 15 feet thick. When these beds are less than 4 inches thick the rocks lose the novaculite character, and are more like flinty shales. When examined under the microscope the rock is found to present a very uniform appearance, and to consist of extremely minute interlocking grains of cryptocrystalline silica. Chemical tests show that this silica is quartz and not amorphous silica. Thin sections also disclose the presence of numerous cavities in the rock quarried for whetstones. These cavities have been found to present a rhomboidal

outline, and to correspond in form and position to included patches of calcite found in the same rock where the bed passes beneath the creek levels. It has been assumed that these cavities are formed by the dissolution and removal of the calcite, and as the material from beneath the water level is of slight value as a whetstone it has been reasoned that the abrasive qualities of the Arkansas stone are due to the presence of these calcite cavities. The origin of the rock has been the subject of considerable speculation from the earliest times to the present. It has been commonly asserted that it is a very fine-grained sandstone, which has been indurated and altered by hot-spring action. This explanation is not adequate, however, since the same beds are exposed on the flanks of the Ouachita Mountain system for a total length of several hundred miles. Moreover, the character of the grains does not permit the assumption that they were originally rounded and that the spaces between have been filled by secondary deposition of silica, as is commonly the case with many quartzites. The writer's belief is that the evidence supports the opinion that the rocks were formed as a chemical precipitate in the deep seas of a Silurian ocean, and that comparatively little alteration beyond induration has taken place. Such a theory seems to accord very well with the chemical and physical nature of the rock and with the facts now known in regard to the origin of some of the early geologic sediments.

Igneous rocks.—Besides the sedimentary rocks just noted, there are four narrow dikes of igneous rock about one-half mile south of the mountain borders and near the city limits. These rocks are dark-colored mica traps, a form of rock called "ouchatite." They are chiefly interesting because they show that there was some deep-seated body of molten material from which the dike fissures were supplied. Small dikes are found north of the city, east of the city, and in considerable abundance about Potash Sulphur Springs and at Magnet Cove. These dikes have a generally east-southeast-west-northwest direction, showing that the fissures are parallel to the mountain sides. They are from 1 to 4 feet wide and are generally much altered, so that the outcrop is inconspicuous or is covered by vegetation. When the rock is broken black mica in small flakes is the only mineral seen.

Fossils.—The age of the sedimentary rocks is determined by the fossil remains found in them. The black shales which underlie the novaculites contain remains of a curious hydrozoa. These fossil remains are known as graptolites, and the forms identified at Hot Springs belong to the upper part of the lower Silurian age (Trenton and Utica). New types of these fossils peculiar to Hot Springs are illustrated in the novaculite report issued by the Arkansas Geological Survey. Besides these curious forms, a few shell remains (brachiopods and lamellibranchs), corals, and worm trails have been found.

The graptolites occur on the north side of the hill on a small stream drainage on the west side of the continuation of Park avenue. They are also seen in a very black shale forming the bluff on the west side of Park avenue above Hotel Hay and below the Barnes House. Similar fossils also occur on Whitington avenue, one-fourth of a mile above the head of Central avenue, at a point where the street crosses the creek.

Plant remains of lower Carboniferous age have been found in the shales exposed in the excavation for a cellar on the western side of Malvern avenue, 100 feet north of the Park Hotel. The shales are varicolored, brown, red, gray, and black, but the fossils occur in the olive-colored sandy shales. Similar fossils were also found in Ouachita avenue at Hot Springs.

WATERS OF THE HOT SPRINGS.

OCCURRENCE.

The hot waters issue from the base and lower portion of the slopes east of the valley. This area is a narrow strip, a few hundred feet wide and one-fourth mile long. In its general aspect this area is distinguished from the rest of the mountain by its patches of barren gray tufa, the old hot-spring deposit, and the absence of forest growth. From the descriptions given by earlier writers it is evident that this difference in appearance and vegetation was formerly very marked. To-day the springs are all covered, and mostly concealed beneath turf and shrubbery. The old tufa deposit is in large part covered by soil and plants. The creek is arched over and sidewalks and roadways are built on it. The space between creek and hillside is covered by the bathing establishments, which, in many instances, are built directly over large springs. The landscape gardener has modified the old slopes, filled up the gullies, and built roads and footpaths until the hot-spring area is a beautiful park and a fitting setting for the springs.

It is difficult for the average visitor of to-day to form an idea of the natural appearance of the springs. The larger springs formerly issued abruptly from the tufa slopes and did not possess the bowls and basins seen at the Mammoth Hot Springs of the Yellowstone. An artificial cutting made into the mound of the Cave Spring shows a section of the hot-spring deposit, and if the door be opened the waters will be seen flowing into the basin cut to collect them, and depositing creamy alabaster-like tufa and the brilliant emerald-green tufa whose color is due to the growth of hot-water algæ. Many of the smaller springs are mere oozes, with no well-defined channel. A considerable number of these are gathered into one reservoir at the base of the tufa bluff between the Arlington Hotel and the Superior bath house. Another spring is seen near the Hale

bath house, where it issues from a cavity in the tufa and flows into a basin. There is constant flow from the tufa wall back of this masonry platform, forming the dripping spring, where thousands of visitors daily drink hot water direct from the rock. At this place also the green algous growth may be seen.

TUFA DEPOSITS OF THE HOT SPRINGS WATERS.

As already noted, the hot-spring area is characterized by a deposit of calcareous tufa, or travertine, formed by the hot waters, and covering not only a large part of the mountain slope about the existing hot springs, but also extending westward to the Happy Hollow ravine and occurring above the band stand, far above any existing springs in the slope. Tufa deposits are common about both hot- and cold-water springs whose waters carry carbonate of lime in solution. This material is precipitated when the carbon dioxide of the waters escapes upon exposure of the water to the atmosphere. At the Arkansas hot springs a very small amount of carbonate of lime is held in the waters, yet it is sufficient to coat the hot-water pipes and to fill wooden troughs used to conduct the waters. In Cave Spring and at Dripping Spring the tufa may be seen now forming. It is therefore not certain that the waters which formed the great tufa deposits of the place were any richer in lime carbonates than those of to-day. This tufa is seen in its natural state at many places about the springs, but is particularly well seen at Cave Spring, back of the Arlington Hotel. It is of a gray color and porous texture on the surface, but when quarried is pure white, compact, and crystalline.

This tufa consists almost wholly of carbonate of lime, carrying very small and varying amounts of manganese (oxide) and iron oxide. The manganese is frequently prominent as a black powder, or occurs in blackish layers through the rock. The analysis made for Owen in 1859 of the material deposited in the pipe accords so exactly with that of the deposit now forming that it is reproduced:

Analysis of hot-spring tufa formed in pipes carrying hot water to bath houses.

	Per cent.
Carbonate of lime	92.620
Sulphate of lime	.085
Carbonate of magnesia	3.060
Carbonate of iron	.210
Carbonate of manganese	.190
Potassa	.107
Silica	.119
Total	99.391

In Cave Spring the freshly deposited tufa is tinted orange by the algæ that live in hot water, and green by the species that flourish at slightly lower temperatures. These colors are purely vegetable and disappear if the deposit be heated.

This tufa deposit covers an area of approximately 20 acres, and varies from a few inches to 6 or 8 feet in thickness. Its occurrence shows that some of the springs formerly flowed to the west and that the waters covered a larger area than at present.

The broad area covered by the tufa does not mean that the hot waters covered this entire area at any one time, for the algous growth described as filling the hot-water streams causes a filling up of the channel and a diversion of the water to a different place. In two instances the waters built up mounds about the springs. The most noticeable of these is that of Cave Spring, which has been artificially breached in the development of a larger water supply from the spring. Above the music pavilion another area of tufa indicates the former presence of springs at a level higher than any now existing.

The thickness of the tufa deposit is likely to be overestimated, as it covers steep slopes and even forms cliff faces. The earliest description of the place tells of its forming overhanging masses alongside the creek, whose flood waters swept away its support. The natural exposures of conglomerate and sandstone outcropping near the pavilion show that the tufa is there underlain by hard rock. Farther west, however, the tufa overlies soft, shaly rocks, which have been digested by the hot waters and vapors for so long a time that the material is as soft as ashes. In the development of new water supplies near Spring No. 1 a pipe was driven 38 feet down into this material. Immediately beneath the tufa there is a breccia of novaculite sandstone or shale fragments cemented by iron oxide, manganese oxide, and carbonate of lime. This is seen under the tufa at Cave Spring and at Dripping Spring. It merely represents the old hillside débris cemented by the hot-water deposit and material deposited later beneath the tufa mantle.

The owners of the Hale bath house have cut a short tunnel into the tufa back of their establishment, and the natural heat of the ground is used for a vapor bath. There is no doubt that the ground back of Bath House Row is permeated by a network of fissures and is heated by hot-water vapors.

The tufa area is described by all earlier writers as being distinguished from the adjacent slope by its peculiar vegetation. In the improvement of the reservation this distinction has been largely obliterated, as flowers and shrubs have been freely planted. The tufa cliffs and rougher exposures show, however, the limestone-loving ferns *Cheilanthes alabamensis* Kunze and *Adiantum capillus-veneris* L., which occur nowhere else in this region. Owen mentions these ferns especially, besides numerous peculiar mosses and algæ, stonecrop, sage, lobelia, and senna as characteristic of the tufa area.

GEOLOGIC RELATIONS OF THE HOT SPRINGS WATERS.

In the geologic sketch already given the rocks from which the hot waters issue are described as sandstones and shales of lower Silurian age, occurring in sharply compressed folds. The hot waters issue from the sandstones seen well exposed back of the superintendent's office and near the music pavilion and from the overlying shales in the area west of the pavilion. These rocks form part of a steeply dipping anticline plunging beneath the surface toward the southwest. It may be compared to the partly buried prow of an upturned boat. The rocks arch around the mountain slopes, the different beds being revealed very much as the scales of an onion bulb are exposed when it is partly cut into. While the rocks are flexed into this great curve, the great and thick beds of hard sandstone and conglomerate were cracked while being flexed, and little slips and breaks were produced. The smaller cracks form a network of fractures, which in some places are seen to be filled with white quartz. The principal springs are arranged along a line running about north-northeast, or parallel to the axis of the fold forming Hot Springs Mountain. This line is believed to be a fissure corresponding to a fracture of the northwest fold—a fault fissure. Springs are common along such fractures in the novaculite region of Arkansas, and there is no reason to believe there is anything unusual in this one. The source of heat is discussed elsewhere.

COMPOSITION OF THE HOT SPRINGS WATERS.

Analyses.—The hot springs yield waters of remarkable purity. This, in fact, is the reason ascribed by some physicians for the efficacy of the water as a remedial agent. The very complete analyses given in this report show a very small amount of mineral matter. The purity of the natural waters of the region is well known. The water of Happy Hollow Spring has less mineral matter than any other of the waters known, except that of Poland Spring, of Maine. These waters rise through siliceous rocks, and the fact that the hot waters contain so little mineral matter, particularly silica, is evidence of their meteoric origin, and accords with the nature of the gases given off by the springs.

A direct comparison of the analyses with those made in earlier years is not convenient, since the analyses are given in parts per million, while those of the Arkansas Geological Survey are in grains per gallon. I have recalculated the analyses of the larger springs, however, and find them nearly identical with the later ones, showing conclusively that the nature of the waters is not changing with time.

The accompanying table gives a recapitulation of the analyses made by Mr. J. K. Haywood, of the Department of Agriculture:

Table of flows, temperatures, and analyses of waters of Arkansas hot springs.[a]

[In parts per million.]

Springs.	Degrees F.	Flow in gallons per 24 hours.	SiO_2.	SO_4.	HCO_3.	NO_3.	NO_2.	PO_4.	BO_2.	Cl.	Br.	I.	FeAl.	Mn.	Ca.	Mg.	K.	Na.	Li.	NH_4.	Total parts per million.
Egg	143.4	28,800	45.11	7.83	166.50	0.88	Trace.	Trace.	(b)	2.50	Trace.	Trace.	0.24	0.36	46.09	4.81	1.65	4.52	Trace.	0.302	280.792
Arsenic	129.0	c10,800	44.48	8.24	160.50	.44	Trace.	Trace.	(b)	2.50	Trace.	Trace.	.24	Trace.	44.64	4.77	1.98	4.46	Trace.	.060	272.310
Arlington	143.1	19,938	44.89	7.76	166.60	Trace.	0.0007	Trace.	(b)	2.50	Trace.	Trace.	.28	.22	46.36	4.88	1.65	4.52	Trace.	.02	279.6287
Cliff	132.6	3,600	43.55	8.63	160.50	.44	.0013	Trace.	(b)	2.38	Trace.	Trace.	.35	.22	44.61	4.68	2.01	4.48	Trace.	.043	271.8943
Avenue	143.4	17,280	44.31	7.85	166.50	.44	.0022	Trace.	(b)	2.38	Trace.	Trace.	.28	.22	46.58	4.58	1.65	4.51	Trace.	.084	279.3862
Boiler House	136.9	32,400	44.51	8.50	163.50	.75	.0013	Trace.	(b)	2.75	Trace.	Trace.	.21	Trace.	46.25	4.88	1.68	4.50	Trace.	.025	277.5563
Imperial (north)	141.4	d18,514	44.59	7.92	169.60	.33	.0041	Trace.	0.86	2.50	Trace.	Trace.	.35	.18	47.23	4.99	1.70	4.57	Trace.	.116	284.9401
Crystal	97.2	e2,000	46.28	7.88	172.60	.22	.0012	Trace.	(b)	2.50	Trace.	Trace.	.28	Trace.	48.35	4.90	1.80	4.54	Trace.	.065	289.4162
Rector	144.3	f51,840	44.91	7.60	166.50	.09	.0013	Trace.	(b)	2.50	Trace.	Trace.	.21	.11	46.18	4.97	1.68	4.64	Trace.	.002	279.4533
Cave	135.3	18,514	44.55	7.73	160.50	Trace.	.0016	Trace.	(b)	2.38	Trace.	Trace.	.21	.22	45.07	4.94	1.60	4.37	Trace.	.001	271.6026
Little Iron (north)	134.2	.....	47.44	8.28	160.50	.18	.0012	Trace.	(b)	2.71	Trace.	Trace.	.12	.11	43.84	4.98	1.66	5.18	Trace.	.005	275.0062
Little Geyser	97.2	524	32.52	6.73	93.90	.18	.0008	0.13	(b)	2.43	Trace.	Trace.	.11	Trace.	25.89	3.18	1.31	3.68	Trace.	.025	170.0858
Little Iron (south)	133.3	.....	46.17	8.35	166.50	.18	.0012	Trace.	(b)	2.57	Trace.	Trace.	.11	.12	46.22	4.93	1.60	4.87	Trace.	.043	281.6642
Ral	145.0	8,640	45.17	7.95	166.50	Trace.	.0033	Trace.	(b)	2.36	Trace.	Trace.	.11	.27	46.21	4.84	1.57	4.98	Trace.	.048	280.0113
Big Iron	147.0	201,600	49.59	7.84	168.10	.44	.0016	.05	1.29	2.53	Trace.	Trace.	.19	.34	46.93	5.10	1.60	4.76	Trace.	.040	284.8016
Imperial (south)	141.6	.....	43.88	7.67	163.50	.27	.0010	Trace.	(b)	2.36	Trace.	Trace.	.09	.29	45.50	4.81	1.60	4.61	Trace.	.028	274.6000
Arsenic (north)	133.5	.....	45.67	8.58	163.50	.44	.0020	Trace.	(b)	2.36	Trace.	Trace.	.09	Trace.	45.40	4.70	1.88	5.12	Trace.	.037	277.7790
Hitchcock	135.2	g35,000	44.74	10.63	162.00	1.55	.0016	Trace.	(b)	2.57	Trace.	Trace.	.09	Trace.	46.04	4.94	2.01	4.79	Trace.	.057	279.4186
Sumpter	133.5	13,292	44.35	8.75	159.00	1.33	.0010	Trace.	(b)	2.57	Trace.	Trace.	.09	Trace.	44.72	4.71	2.00	4.58	Trace.	.011	272.1120
Superior (north)	115.3	3,677	39.90	7.31	133.20	.31	.0010	.13	(b)	2.43	Trace.	Trace.	.09	.11	37.43	4.23	1.47	4.40	Trace.	.013	231.0240
Alum	114.8	1,152	45.56	7.95	166.50	Trace.	.0013	Trace.	(b)	2.57	Trace.	Trace.	.09	.11	45.97	4.84	1.65	5.59	Trace.	.009	280.9043
Superior (south)	134.8	1,723	44.79	8.03	162.00	Trace.	.0055	Trace.	(b)	2.43	Trace.	Trace.	.09	.18	44.73	4.76	1.64	4.67	Trace.	.025	273.3505
Twin (north)	144.3	f10,800	46.25	7.97	167.60	Trace.	.0010	Trace.	(b)	2.43	Trace.	Trace.	.09	.16	46.92	4.82	1.74	5.11	Trace.	.032	285.1230
Twin (south)	144.1	.....	46.85	7.81	168.80	Trace.	.0008	Trace.	(b)	2.83	Trace.	Trace.	.22	.15	46.75	4.92	1.74	4.78	Trace.	.035	284.8858
Old Hale	144.8	g35,000	47.31	7.80	166.50	Trace	.0007	Trace.	(b)	2.50	Trace.	Trace.	.19	.29	46.82	5.01	1.69	4.73	Trace.	.028	282.8687
Palace	146.1	25,847	47.86	7.82	166.50	Trace.	.0008	Trace.	(b)	2.50	Trace.	Trace.	.19	Trace.	46.75	4.99	1.74	4.80	Trace.	.021	283.1718

Tunnel	125.4	800	49.95	7.98	146.70	.22	.0010	Trace.	(b)	2.58	Trace.	Trace.	.16	.14	39.61	4.95	1.73	4.66	Trace.	.037	258.7180
Maurice	139.6	g21,000	47.41	7.80	165.00	.27	.0008	Trace.	(b)	2.58	Trace.	Trace.	.21	.15	45.47	4.82	1.76	4.89	Trace.	.061	280.4218
Dripping	136.0	2,618	48.02	7.64	165.00	.22	.0003	.80	(b)	2.58	Trace.	Trace.	.22	.15	45.97	4.80	1.67	5.09	Trace.	.010	282.0203
Arch	129.0	(h)	50.90	7.50	157.50	.44	.0020	Trace.	(b)	2.67	Trace.	Trace.	.12	Trace.	43.00	4.92	1.72	4.99	Trace.	.011	273.7730
Haywood	124.5	67,200	47.40	8.78	162.00	.34	.0008	Trace.	(b)	2.67	Trace.	Trace.	.19	.25	45.45	4.72	1.65	4.69	Trace.	.042	278.1828
John W. Noble	115.7	28,800	48.27	8.29	159.00	.34	.0013	Trace.	(b)	2.50	Trace.	Trace.	.19	.12	44.75	4.73	1.72	4.94	Trace.	.023	274.8743
Lamar	120.6	.....	49.60	8.53	165.00	Trace.	.0013	Trace.	(b)	2.50	Trace.	Trace.	.22	.15	45.94	4.80	1.68	4.65	Trace.	.042	283.1133
H. W. Wiley	118.2	28,800	46.90	8.08	163.50	Trace.	.0016	Trace.	(b)	2.67	Trace.	Trace.	.24	.04	45.68	4.73	1.69	4.84	Trace.	.045	278.4166
Ed. Hardin	109.4	2,469	46.57	7.49	165.00	1.33	.0013	Trace.	(b)	2.50	Trace.	Trace.	.19	.20	46.32	4.79	1.70	4.65	Trace.	.023	280.7643
Eisele	120.0	9,600	48.84	8.71	163.50	.78	.0007	Trace.	(b)	2.58	Trace.	Trace.	.19	.11	46.33	4.92	1.68	4.70	Trace.	.023	282.3637
Stevens	127.2	5,760	46.65	15.78	169.60	Trace.	.0013	Trace.	(b)	2.67	Trace.	Trace.	.14	.08	49.93	5.07	1.76	5.28	Trace.	.036	296.9973
Horse Shoe	139.6	g40,000	49.81	7.86	171.10	Trace.	.0005	Trace.	(b)	2.50	Trace.	Trace.	.26	.27	46.61	5.07	1.60	5.42	Trace.	.030	290.5305
Army and Navy	142.5	35,000	50.51	9.41	169.60	1.33	.0030	Trace.	(b)	3.33	Trace.	Trace.	.28	.14	47.11	5.14	1.93	5.98	Trace.	.111	294.8740
W. J. Little	120.0	4,320	45.73	7.76	163.50	Trace.	.0010	Trace.	(b)	2.67	Trace.	Trace.	.19	Trace.	45.43	4.96	1.59	5.00	Trace.	.008	276.8390
Mud	118.9	g4,000	52.30	11.95	168.10	.44	.0016	Trace.	(b)	3.17	Trace.	Trace.	.29	Trace.	46.89	5.22	2.23	6.49	Trace.	.018	297.0996
Magnesia	136.9	g50,000	49.63	8.40	166.50	.44	.0008	Trace.	(b)	2.83	Trace.	Trace.	.33	.07	45.93	5.19	1.72	5.08	Trace.	.058	286.1788
Reservoir	115.3	g20,000	43.21	28.67	160.50	.22	.0013	.53	(b)	5.83	Trace.	Trace.	.44	None.	49.22	4.24	8.84	8.33	Trace.	.008	310.0393
Liver (cold)	46.4	659	12.50	2.50	12.10	.89	Trace.	Trace.	(b)	1.83	Trace.	Trace.	.34	Trace.	1.89	1.36	.94	2.10	Trace.	.009	36.459
Kidney (cold)	55.4	511	15.06	2.29	15.14	.44	.0007	Trace.	(b)	2.00	Trace.	Trace.	.34	Trace.	3.79	1.45	1.02	2.23	Trace.	.021	437.817
Fordyce	124.7	g25,000	49.16	8.21	166.50	(j)	(j)	.33	(b)	2.50	Trace.	Trace.	.18	.21	45.79	5.06	1.57	5.26	Trace.	(j)	284.77

[a] J. K. Haywood, analyst. [b] Small amount. [c] Includes Arsenic spring (north). [d] Includes Imperial spring (south). [e] Includes Little Iron spring (north) and Little Iron spring (south). [f] Includes Twin spring (south). [g] Estimated. [h] Could not be estimated. [i] Includes Lamar spring. [j] Not determined.

AsO_4 was tested for, but not found in any of the waters.

Gases.—The gases given off by the hot waters were carefully collected and analyzed. The results show that they consist of carbon dioxide, oxygen, and nitrogen. The ratio of oxygen and nitrogen corresponds very closely to that of atmospheric air, and, taking into account the relative absorption of the two gases by water, there can be no doubt that the oxygen and nitrogen given off by the water came from absorbed air.

Mineral contents.—The mineral matter of the waters has come from the rocks traversed by the waters. Recollecting the solvent power of hot water, it is rather remarkable that the waters are so pure. The underlying rocks are Silurian sediments resting on an unknown complex, but the Silurian rocks alone are competent to supply all the mineral matter of the waters.

SOURCE OF HOT SPRINGS WATERS.

From what has already been said in discussing the geologic and topographic relations of the springs, and from the composition of the water and of the gases, there seems no doubt that the hot springs correspond closely to the ordinary springs of the mountain region save in the very important element of heat. As will be shown later, it is believed that the waters of a very large but entirely normal spring or springs have been heated by vapors rising through fissures penetrating to unknown depths.

DURATION OF THE HOT SPRINGS.

Temperatures.—The question whether the hot springs are changing in character and will eventually either cease flowing or become cold springs is of both popular and scientific interest. In 1804 Dunbar and Hunter recorded a temperature of 150° F. for the larger spring and 154° F. for another spring. In 1859 the springs were carefully examined by David Dale Owen, State geologist, and a map of temperatures and elevations was published. In 1860 a more accurate map, together with records of temperature and outflow, was prepared by William Glasgow, jr., from careful instrumental surveys.

Since then many changes have been made about the springs, all of which have been dug out and inclosed in masonry arches, with the consolidation of two or more springs into one in some instances, the development of new outflows by digging wells or sinking pipes, and the drying up of adjacent natural outflows. For these reasons all the springs now existing can not be positively identified with those shown on the earlier maps, but a majority of them are so correlated without doubt.

The comparison of the old records mentioned with those recently made shows that the highest temperature known to-day is 147° F., as against 154° in 1804 and 150° by Glasgow and 148° by Owen in 1860. In a number of springs there is a decline of 2° since the latter

date. Such a slight difference might, however, be due to differences in the manner or place of taking the temperatures, or the instruments used in the earlier years may not have been accurate. It is noteworthy that Owen's highest temperature, taken in 1859 with a standardized thermometer, was 148°, and that recorded now is 147°. In other words, the temperature is decreasing so slowly that the change is almost imperceptible in half a century. In one instance, that of Alum Spring, there is a very marked decrease in temperature, and as this is the only spring on the west side of the creek there is no doubt of its identity. In 1804 this had a temperature of 132°. In 1859 its temperature was 133°, according to Owen, and to-day it is but 114.8°.

Amount of outflow.—The comparison of outflow is more difficult. According to Dunbar and Hunter, the largest spring had an outflow of 11 quarts in eleven seconds in 1804, corresponding to 22,100 gallons per day, and the four largest springs had an outflow of 165 gallons per minute, or 237,600 gallons per day. Doctor Owen gives no measurements, but Glasgow gives the discharge of each spring—a total of 317 gallons per minute, or 450,480 gallons per day, as compared with 850,000 gallons per day at the present time. As the writer has shown elsewhere, the spring water is of meteoric origin, like most spring water, and probably varies somewhat from year to year, corresponding to variation in annual rainfall in some previous year, so that no definite comparison can be made with the early records, except to state that the volume of water discharged is very much greater. Supposing a practically constant amount of heat applied, this of itself would mean a slightly lowered temperature. In this connection attention should be called to the well put down by Major Torney, U. S. Army, in the Army and Navy Hospital, which is capable of yielding the amazing amount of 350,000 gallons per day without affecting but one very small spring (No. 40 of the list).

From a consideration of all these facts it is concluded that the springs are losing their heat so slowly that the loss is almost inappreciable.

Amount of mineral matter in solution.—No essential difference in the composition of the waters can be detected by a comparison of the analyses made for Owen or Larkin (1859) or for Doctor Branner, of the Arkansas Geological Survey, in 1889, with the elaborate and careful analyses made by the National Government. The waters are remarkable more for their purity than for their mineral contents. The material in solution consists mainly of bicarbonate of lime, which is so easily precipitated by the loss of carbonic-acid gas that a deposit forms in pipes, and rather rapidly where the spring waters drip, as in the walls about the bowl of Cave Spring. The total mineral matter for all the springs amounts to 1,367 pounds a day,

equivalent to 249.5 tons a year. This amount of material carried by the hot water from the earth's interior to the surface must leave a very considerable cavity in the course of time.

HEAT OF THE HOT SPRINGS WATERS.

While there have been many theories advanced to account for the source of the hot waters, the only hypothesis that stands the test of scientific inquiry is the one which ascribes the heat of the waters to still hot but concealed bodies of igneous rock. It seems scarcely necessary to call attention to the absurdity of the idea that either slaking lime in the depths of the earth or chemical reaction of the waters with the atmosphere could be the cause of the heat. That the waters come from a depth sufficient for their heating by the normal increment of earth heat (1° for every 50 feet) seems unreasonable, since it would necessitate a depth of nearly 5,000 feet to give the waters their present temperature, even assuming that they were not cooled in their course upward. The composition of the gases given off by the waters shows that they contain atmospheric air as well as carbon dioxide. That the heat of the waters is due to the heat developed by the folding of the rocks, which is the theory given to account for the heat at the Virginia Hot Springs, is not probable, for the folding at Hot Springs is not more intense than elsewhere in the mountain regions of Arkansas, and no evidence of hot-spring action has been found at any other localities except where igneous rocks are present.

It is believed that the heat comes from a great body of still heated igneous rocks intruded in the earth's crust by volcanic agencies and underlying a large part of central Arkansas. The existence of such a mass is shown by the great bodies of granite seen at Potash Sulphur Springs and Magnet Cove, where the rocks have been exposed by the wearing down of the overlying sediments, though the igneous rocks seen were of course long since cooled. At Magnet Cove, moreover, there are tufa deposits which show the former occurrence of hot springs.

This hypothesis is strengthened by the occurrence of intrusive dikes at various localities about the springs, and their trend and occurrence indicate that the molten material which filled the fissures did not come from the bodies of rock now exposed at Potash Sulphur Springs or at Magnet Cove, but had some deep-seated source, whose location is indicated by the dikes as being approximately under the Hot Springs. Deep-seated waters converted into vapors by contact with this "batholith" of hot rock probably ascend through fissures toward the surface, where they probably meet cold spring waters which are heated by the vapors. As the igneous dikes near by are fissures reaching down to this great mass of igneous magma, which have been filled by it to form dikes, it is not unreasonable to suppose that fissures extend down to the now solid but still hot igneous mass.

NOTES ON CERTAIN LARGE SPRINGS OF THE OZARK REGION, MISSOURI AND ARKANSAS.

Compiled by MYRON L. FULLER.

The following account is based on memoranda furnished by E. Johnson, jr., who measured the flow of the springs in connection with stream measurements in the same region, and on geologic and other notes furnished by H. Foster Bain and E. M. Shepard. The investigations and measurements of the springs were made with the view of determining their availability as a source of water power, a question which had become of importance because of the needs of such power for plants contemplated in connection with the proposed construction of an electric railway through the district. The account is presented for the purpose of calling attention to the size, character, and importance of the springs which are typical of the Ozark region.

OZARK REGION IN MISSOURI.

GEOLOGY.

The springs which are described in the following pages are, with the exception of Mesamer and Boiling springs, situated on the south flank of the Ozark uplift, where a long structural slope opens the way for an important underground circulation, fed from a central table-land. The springs are in canyons where the streams have cut down into the rock and intersect some aquifer or water-bearing bed. The country rock is generally a cherty dolomite with irregular beds of sandstone, but the particular horizons which are most favorable aquifers have not been discriminated. The rocks are mainly lower Ordovician, but some Cambrian rocks of similar lithologic character occur in the vicinity.

Mesamer Spring is on the north flank of the Ozarks, well up toward the crest, but is in a dolomite and sandstone country of approximately the same age as that of the springs on the south flank of the mountains. Sink holes abound in the region. Boiling Spring is likewise on the northwest flank of the Ozarks, and is said to issue from a dolomitic rock, probably the Gasconade limestone.

GENERAL CONDITIONS.

The country as a whole is a plateau deeply cut by stream erosion, and underground circulation is unusually important. There are many deep, wide valleys which now contain no streams except in very wet weather, all the water going underground within a very short distance. This is so true that the value of the land for stock purposes, the main use except for timber, is largely determined by the presence or absence of springs. These are numerous, those described being only some of the best known. Intermittent as well as steady-flowing springs occur. One of the best known is in Shannon County, near the junction of Jacks Fork and Current River. This spring has a rhythmic flow with maxima approximately forty minutes apart. The minimum flow is much less than the maximum, but the water does not altogether cease flowing. Presumably the spring is the outlet of two or more underground channels, one of which has a chamber and siphon form.

All of the springs show marked fluctuation of discharge with variations in rainfall, which probably accounts for the great difference in past and present flows, such as is noted in the case of Blue and Alley springs.

DESCRIPTION OF SPRINGS.

Greer Spring.—This spring, which is owned by Greer & Mainprize, is located in sec. 36, T. 25 N., R. 4 W., 1½ miles northeast of Greer post-office and about the same distance south of Eleven Point River. It is 8 miles northeast of Alton, the county seat of Oregon County, and 16 miles due south of Winona, Shannon County. About one-fourth its water issues from a cave lined with stalactites and stalagmites, situated at the head of a deep ravine cut in Ordovician rocks, mainly cherty dolomites, with occasional irregular beds of sandstone. The remaining three-fourths comes from a so-called "boil" 100 feet distant and 7 feet lower, the source of which is invisible. From the spring the water flows down a rapid descent through a narrow valley to Eleven Point River, 54 feet lower, furnishing power for a large gristmill on the way.

The water is colorless, except where contaminated by sediment washed in below its source in time of storm. It has no odor or taste and has a temperature of 54°. Other than the source of power mentioned, no use is made of its waters.

The maximum measurement of flow gave a result of 362 cubic feet per second, while the minimum flow is not far from 225 cubic feet. About 265 feet is a more common discharge. The minimum flow is equal to that of a stream 25 feet wide, 3 feet deep, flowing 3 feet per second, and represents the run-off of a large area of surface.

Van Buren or Big Spring.—This is located in the valley of Current River, 4 miles southeast of Vanburen, the county seat of Carter County, and has a large flow.

Fanchon Spring.—Fanchon Spring is located on the side of the left bluff of Current River, in sec. 9, T. 29 N., R. 2 W., 10 miles east of Eminence, the county seat of Shannon County. The spring is owned by a hunting and fishing club of St. Louis, and is said to yield sufficient water for power purposes.

Alley or Big Spring.—Alley Spring is located near Alley post-office, in T. 29 N., R. 5 W., about 6 miles west of Eminence, Shannon County. It emerges as a stream from the base of a high dolomitic limestone bluff on the side of the comparatively broad valley of Jacks Fork, a tributary of Current River, with which its waters unite about one-half mile below the spring.

The water is odorless, tasteless, somewhat hard, and has a temperature of 53°. Its ordinary flow is 85 cubic feet per second, but is probably not more than 75 second-feet during the summer. It furnishes power for a grist and saw mill near its source. The flow of this spring in 1875 was reported by Dr. C. P. Williams[a] as 588 second-feet.

Blue or Round Spring.—This spring is located in sec. 20, T. 30 N., R. 4 W., about 14 miles northwest of Eminence. It originates in a natural limestone well about 84 feet in diameter at the rim and 48 feet deep. On one side is a high bluff; through an opening on the other side, 18 feet below the surface and 72 feet in length, the water escapes and flows into Current River, a quarter of a mile distant.

The water is odorless and tasteless and of a deep-blue tinge. The temperature is 54°. As given by Dr. C. P. Williams,[a] the flow in 1875 was 425 cubic feet per second, but when measured in 1904 by Mr. E. Johnson, jr., was only 23 second-feet. It has in the past furnished power to at least two mills, but no use is now made of it.

Mesamer Spring.—This spring, which is owned by the James estate, is located in sec. 17, T. 37 N., R. 6 W., 7 miles in a southerly direction from St. James. The spring issues as a subterranean stream from the base of a bluff in a gorge in the Gasconade limestone. The water is of a bluish tinge, without odor or taste, but fairly hard, and carries some sediment after heavy rains. Its temperature is 56°. The flow is affected by rainfall. According to the reports of the Tenth Census it then had a flow of 100 to 150 cubic feet per second, while on August 18, 1900, it had, according to H. B. Shaw, a flow of 125 second-feet. The minimum flow determined in 1904 by Mr. E. Johnson, jr., of the United States Geological Survey,

[a] Industrial Rept. Geol. Survey Missouri, 1877, p. 160.

was 86 second-feet. It has been utilized as a water power in the past and has been considered as a source of water supply for the city of St. Louis in connection with Water Fork of Meramec River, into which it flows at a point about one-half mile from its source and 12 feet lower down. The maximum combined flow of the two streams has been found by Mr. Johnson to be 150 second-feet.

Boiling Spring.—Boiling Spring is located in T. 36 N., R. 10 W., 6 miles in a southerly direction from Arlington post-office. It issues from the bed and bank of Gasconade River, near the base of a high dolomitic limestone bluff. Its water is of a bluish tinge, without odor or taste, but rather hard. It is not especially muddy even after rains. The temperature is 60° and the flow about 150 second-feet, but no use is now made of the water either for power or other purposes.

OZARK REGION IN ARKANSAS.

DESCRIPTION OF MAMMOTH SPRING.

Mammoth Spring, which is owned by Napoleon Hill and the heirs of J. W. Cochran, is located near the line between secs. 5 and 8, T. 21 N., R. 5 W., about one-eighth mile in a northerly direction from Mammoth Spring post-office. It issues as a subterranean stream near the base of a high cherty limestone bluff ("Third Magnesian limestone" of Swallow). The course of the underground river feeding the spring is thought to be marked in Howell County, 8 miles northwest, by a sink hole three-fourths mile long known as the "Grand Gulf." The spring itself is 64 feet deep at its mouth, the water apparently issuing from a large cavernous opening and from other large crevices in the rock.

The water is described as having a bluish tinge, but as being odorless and tasteless, and having a temperature of 58° or 59° in summer. The amount of water is somewhat affected by prolonged droughts, the water level varying 3 or 4 inches. The water is hard, having about 158 parts per million of lime and 139 parts of magnesia. Carbonic acid to the amount of 204 parts per million is reported.

The flow has been reported to be as high as 350 second-feet, but in 1904 it was as low as 150 cubic feet per second. This is, however, probably about its minimum volume. A large hotel has been constructed and a park laid out at the springs. The water is now used for power by a flour and cotton mill and further developments are contemplated.

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The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the forty-sixth in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls.
WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls.
WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls.
WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.
WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp.
WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls.
WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls.
WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp.
WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls.
WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp.
WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls.

WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96-140 pp.

WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp.

WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls.

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

WS 77. Water resources of Molokai, Hawaiian Islands, by W. Lindgren. 1903. 62 pp., 4 pls.

WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their use for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.

WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.

WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.

WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls.

WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879-1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 196 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 8 pls.

WS 140. Field measurements of the rate of movement of underground water, by C. S. Slichter. 1905.

WS 141. Observations on the ground waters of the Rio Grande Valley, 1904, by C. S. Slichter. 1905.

WS 142. The hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 12 pls.

WS 145. Contributions to the hydrology of eastern United States, 1905; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

OCTOBER, 1905.

Water-Supply and Irrigation Paper No. 146

Series { I, Irrigation, 19
J, Water Storage, 12

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PROCEEDINGS

OF

SECOND CONFERENCE OF ENGINEERS OF THE RECLAMATION SERVICE

WITH ACCOMPANYING PAPERS

COMPILED BY

F. H. NEWELL

CHIEF ENGINEER

IELAND STANFORD JUNIOR
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GOVERNMENT PRINTING OFFICE

1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., April 26, 1905.

SIR: I transmit herewith a manuscript relating to the conference of the engineers of the Reclamation Service held at El Paso, Tex., November 14 to 18, 1904, and adjourned to Washington, D. C., where the conference was continued from January 9 to 14, 1905.

This second conference was in continuation of the general policy of holding annually a meeting of the principal engineers of the Reclamation Service, largely for the purpose of discussing matters of administration and economies of work. The first conference was held at Ogden, Utah, September 15 to 18, 1903, in connection with the Eleventh Irrigation Congress, held at that time and place. The first session of the second conference was held at the time of the meeting of the Twelfth Irrigation Congress, at El Paso, Tex., at which place were gathered citizens representing all of the Western States and Territories interested in the development of irrigation. The bringing together at El Paso of the principal engineers of the Reclamation Service and of prominent citizens from the West made possible an interchange of views and a discussion of data leading to results of very great value in the furtherance of the purposes of the reclamation act.

At El Paso the engineers took part in the proceedings of the engineering section of the Irrigation Congress, and also held meetings of a more or less executive character to consider and make recommendations concerning important details of the work. Various conditions were pointed out and discussed; methods of expediting and economizing the various operations were presented; and engineers from various sections of the country compared experiences and exchanged views regarding matters of common interest.

The conference adjourned to meet in Washington in January, in order to allow opportunity for other engineers to take part in the discussions and to give additional time for consideration of important details. At the adjourned meeting in Washington a number of

DIVISION OF HYDRO-ECONOMICS.

Marshall O. Leighton, Washington, D. C., hydrographer in charge, assisted by Horatio N. Parker, assistant hydrographer; Richard B. Dole and Samuel J. Lewis, assistant engineers; Herman Stabler, engineering aid; and Sheldon K. Baker, hydrographic aid, and others.

RECLAMATION SERVICE.

Created by law on June 17, 1902, authorizing the survey and construction of irrigation works for reclaiming arid lands in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming from the proceeds arising from the sale and disposal of public lands.[a] Under the hydrographic branch, but distinct and separate from that body.

Hon. E. A. Hitchcock, Secretary of the Interior; approves all matters and signs all contracts.

Charles D. Walcott, Director of the Geological Survey and of the Reclamation Service; initiates action and reports to the Secretary.

Carl Ewald Grunsky, consulting engineer in the Reclamation Service.

EXECUTIVE AND CONSULTING STAFF.

F. H. Newell, chief engineer, U. S. Geological Survey, Washington, D. C.

Arthur P. Davis, assistant chief engineer, Washington, D. C.

George Y. Wisner, consulting engineer, 34 West Congress street, Detroit, Mich.

J. B. Lippincott, supervising engineer, Braly Building, Los Angeles, Cal.

J. H. Quinton, supervising engineer, Montrose, Colo.

W. H. Sanders, consulting engineer, 915 Grand View avenue, Los Angeles, Cal.

H. N. Savage, supervising engineer, Billings, Mont.

D. C. Henny, supervising engineer, Portland, Oreg.

Charles H. Fitch, supervising engineer, Denver, Colo.

O. H. Ensign, consulting engineer and electrical expert for Pacific coast, 437 South Cummings street, Los Angeles, Cal.

H. A. Storrs, electrical and mechanical expert for Atlantic slope, Chamber of Commerce Building, Denver, Colo.

Morris Bien, supervising engineer (on land and legal matters), Washington, D. C., assisted by J. M. McKinney, examiner, E. H. Peery, law clerk, H. L. Holgate, C. A. Mansuy, and O. G. Cowhick, assistant examiners, and others.

L. H. Taylor, supervising engineer, Hazen, Nev.

Charles E. Wells, supervising engineer, Casper, Wyo.

Charles S. Slichter, consulting engineer, Madison, Wis.

A. J. Wiley, consulting engineer, Boise, Idaho.

T. H. Means, engineer of soils, Salt Lake City, Utah.

B. M. Hall, consulting engineer, El Paso, Tex.

N. H. Darton, geologist, Washington, D. C.

E. T. Perkins, engineer and traveling auditor, Braly Building, Los Angeles, Cal.

George A. Hammond, superintendent of borings, Salt Lake City, Utah.

E. G. Paul, engineer in charge of instruments, Washington, D. C.

C. J. Blanchard, statistician, Washington, D. C.

N. E. Webster, jr., accountant, Washington, D. C.

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[a] Extended to Texas by act of February 25, 1905.

DISTRICT ENGINEERING FORCE.

Arizona.—Louis C. Hill, supervising engineer in charge, Phoenix, Ariz. Chester W. Smith, constructing engineer, Salt River project, Roosevelt, Ariz. Assistants: E. Duryee, cement expert; B. R. Harrison, tunnel expert; F. Teichman, designing engineer; Robert De Large, construction foreman; J. D. Stannard, A. L. Harris, O. T. Reedy, A. M. Sprigg, H. G. Stokes, Hugh Redmond, and W. A. Farish, assistant engineers; A. H. Demrick, electrician; O. L. McIntyre, engineering aid, and others.

California.—J. B. Lippincott, supervising engineer in charge of operations in California and adjacent areas, 1108 Braly Building, Los Angeles. Assistants: D. W. Murphy and Richard Doerfling, engineers; J. R. Prince, draftsman; J. W. Spencer, disbursing agent; C. H. H. Stone, assistant analyst, and others. Homer Hamlin, engineer in charge of Colorado River project, Yuma, Ariz. Assistants: J. C. Clausen, engineer; Paul McGeehan, R. S. Hawley, L. M. Lawson, and M. D. Williams, assistant engineers; J. C. Avakian, draftsman; L. B. Brainard, A. C. Hansen, W. D. Smith, Edward Riesbol, and T. J. Strickler, engineering aids, and others. S. G. Bennett, engineer in charge of Sacramento Valley investigations, 431 Rialto Building, San Francisco. Assistant: Edward Johnson, jr., engineer. W. B. Clapp, assistant engineer in charge of California hydrography, 431 Rialto Building, San Francisco. Assistants: Eugene C. La Rue, O. W. Peterson, and R. J. Taylor, engineering aids, and others. T. H. Humpherys, assistant engineer in charge of Klamath investigations. Assistants: F. W. Huber, assistant engineer, and others.

Colorado.—J. H. Quinton, supervising engineer, Montrose, Colo. C. H. Fitch, Chamber of Commerce Building, Denver; G. H. Matthes, engineer; C. R. Steiner, assistant engineer; J. C. Gawler, disbursing agent; L. F. Kinslow, topographic draftsman; T. E. Brick and Mrs. J. K. Gawler, clerks. I. W. McConnell, engineer in charge of Uncompahgre Valley project, Montrose; J. A. Sargent and C. T. Pease, engineers; E. E. Sands, H. A. Howe, J. L. Lytel, J. T. Keenan, J. M. Roberts, and J. H. Miner, assistant engineers; J. O. Ambler, engineering aid; H. E. Essley, and R. E. Furstenfeld, bookkeepers. M. C. Hinderlider, engineer, Denver, in charge of hydrography in Colorado and adjacent States, and in charge of La Plata Valley project; R. I Meeker, and Oro McDermith, engineering aids.

Idaho.—D. W. Ross, engineer in charge, Boise. Frank C. Horn, constructing engineer, Minidoka project, Minidoka. Assistants: D. G. Martin, engineer; J. L. Savage, Charles B. Smith, Gilbert H. Hogue, Fred Stockton, and J. T. Burke, assistant engineers; R. M. Conner, Leon L. Gay, Ernest A. Bailey, Robert J. Newell, engineering aids, and others.

Kansas.—Charles H. Fitch, supervising engineer, Washington, D. C. Charles S. Slichter, consulting engineer; W. G. Russell, hydrographer, Russell, Kans.

Montana.—H. N. Savage, supervising engineer, Billings, Mont. C. C. Babb, engineer in charge of operations connected with the Milk River project. Assistants: L. E. Granke, engineer; C. T. Prall, A. E. Place, and L. R. Stockman, assistant engineers; W. B. Freeman, engineering aid, and others. R. S. Stockton, engineer in charge of Crow Reservation surveys. Assistants: George E. Stratton and Ernest D. Hendricks, assistant engineers; L. M. Hatch and J. S. Swan, engineering aids, and others. William E. Swift, engineer in charge of Huntley project. Assistants: H. R. Evans, assistant engineer, and others. S. B. Robbins, engineer in charge of Sun River project, Great Falls, Mont. Assistants: F. F. Prendergast, assistant engineer; W. R. Ewing, Gordon Edson, and A. P. Porter, engineering aids, and others.

Nebraska.—C. E. Wells, supervising engineer, Casper, Wyo. John E. Field,

engineer in charge of operations in western Nebraska, Chamber of Commerce Building, Denver, Colo. Assistants: Andrew Weiss, B. E. Hayden, and J. D. Stannard, assistant engineers; P. D. Simpson, W. L. Gorton, E. C. Woodward, and Sam G. Porter, engineering aids; James Dopson, drillman, and others.

Nevada.—L. H. Taylor, supervising engineer in charge of operations in Nevada, Hazen, Nev. Assistants: William Sargeant, A. V. Saph, and Ferd. Bonstedt, engineers; L. M. Holt, assistant engineer; B. B. Smith, engineering aid: C. F. Carpenter, messenger, and others in Hazen office. R. R. McGregor, engineer, and B. E. Forbes, assistant engineer, in charge of construction of divisions 1 and 2 of Truckee canal. Assistants: I. W. Huffaker, assistant engineer; A. H. Schadler, engineering aid, and others. W. S. Russell, engineer in charge of location and construction of lateral canals in Carson Sink Valley. Assistants: D. W. Hays, C. V. Taylor, W. A. Keddie, H. T. Paterson, A. C. Redman, C. H. Southworth, and Walter N. Frickstad, assistant engineers, and others. F. A. Temple, engineer in charge of location of Alkali Flat reservoir supply canal and outlet. Henry Thurtell, State engineer, in charge of hydrography. Assistant: B. E. Corlett, engineering aid. J. C. Coniff, field assistant in charge of topographic survey of irrigable lands. Assistants: A. T. Philips, M. Hayes, and others.

New Mexico.—B. M. Hall, supervising engineer, Carlsbad, N. Mex. Assistant: J. L. Rhead, assistant engineer. W. M. Reed, engineer, Roswell, N. Mex., in charge of operations connected with the Hondo project. Assistants: E. W. Myers, assistant engineer; H. L. Eames and F. S. Dobson, engineering aids, and others. M. C. Hinderlider, engineer in charge of La Plata Valley project, Chamber of Commerce Building, Denver, Colo.

North Dakota.—H. N. Savage, supervising engineer, Billings, Mont. F. E. Weymouth, engineer in charge of Fort Buford project. Assistants: Charles H. Paul and E. C. Bebb, engineers; J. N. Kerr, C. K. Hosford, and H. S. Morse, assistant engineers, and others. H. A. Storrs, electrical engineer, Chamber of Commerce Building, Denver, Colo., in charge of pumping from Missouri River. Assistant: P. M. Churchill, assistant engineer. J. A. French, assistant engineer, in charge of surveys near Bismarck, N. Dak. E. F. Chandler, assistant engineer, University of North Dakota, in charge of hydrography.

Oklahoma.—James G. Camp and W. W. Schlecht, assistant engineers on reconnaissance surveys, under B. M. Hall, supervising engineer, Carlsbad, N. Mex.; Charles E. Gordon, Lawton, Okla., assistant engineer in charge of operations under town-lot fund; G. L. Warner, assistant engineer; L. E. Johnson, engineering aid.

Oregon.—D. C. Henny, supervising engineer. John T. Whistler, district engineer, Pendleton, Oreg., in charge of operations. Assistants: J. H. Lewis, Herbert D. Newell, I. S. Voorhees, Edmund I. Davis, and W. C. Sawyer, assistant engineers; G. Stubblefield, R. S. Hall, W. R. Saxton, and H. S. Williams, engineering aids; N. S. Hamilton, draftsman, and others.

South Dakota.—Charles H. Fitch, supervising engineer, Denver, Colo. Raymond F. Walter, engineer in charge of Belle Fourche project, Belle Fourche, S. Dak. Assistants: H. E. Green, engineer; Frank C. Magruder and Francis M. Madden, assistant engineers; H. D. Comstock, engineering aid, and others.

Utah.—J. H. Quinton, supervising engineer, Montrose, Colo. George L. Swendsen, district engineer, P. O. Box "S," Salt Lake City. Assistants: W. D. Beers, W. P. Hardesty, and Caleb Tanner, assistant engineers; H. W. Sheley, L. L. Hunter, H. S. Kleinschmidt, W. T. Carpenter, T. C. Callister, W. J. Spalding, and W. G. Swendsen, engineering aids, and others.

Washington.—D. C. Henny, supervising engineer. T. A. Noble, engineer in charge, Yakima project, North Yakima, Wash. Assistants: Christian Anderson, engineer; L. J. Charles, F. H. Tillinghast, Charles E. Hewitt, George H. Bliss, assistant engineers; C. C. Fisher, Charles B. Cox, O. Laurgaard, and Calvin Casteel, engineering aids, and others.

Wyoming.—H. N. Savage, supervising engineer for northern portion, Billings, Mont. Jeremiah Ahern, district engineer, Cody, Wyo., in charge of Shoshone project. Assistants: C. P. Williams, designing engineer; D. W. Cole, engineer; W. E. Young, H. J. Saunders, E. S. Ela, and E. F. Tabor, assistant engineers; A. C. Downey, R. S. Sargent, and Carroll Paul, engineering aids, and others. Charles E. Wells, supervising engineer for southern portion. E. H. Baldwin, constructing engineer in charge of Pathfinder reservoir. Assistants: L. V. Branch, assistant engineer, and others.

ACCOUNTS AND PROPERTY.

The hydrographers and engineers named in the following list are authorized to certify accounts for approval by the chief engineer, and are responsible to the chief engineer for the property purchased in the field:

DIVISION OF HYDROGRAPHY.

Eastern section.—N. C. Grover, R. E. Horton, H. K. Barrows, E. G. Paul, M. R. Hall, and F. W. Hanna.

DIVISION OF HYDROLOGY.

Eastern section.—M. L. Fuller.
Western section.—N. H. Darton.

DIVISION OF HYDRO-ECONOMICS.

M. O. Leighton.

RECLAMATION SERVICE AND WESTERN SECTION OF HYDROGRAPHY.

Arizona.—Louis C. Hill.
California.—J. B. Lippincott.
Colorado.—J. H. Quinton.
Idaho.—D. W. Ross.
Kansas.—Charles H. Fitch.
Montana.—H. N. Savage.
Nebraska.—John E. Field.
Nevada.—L. H. Taylor.
New Mexico.—B. M. Hall.
North Dakota.—H. N. Savage.
Oklahoma.—Gerard H. Matthes.
Oregon.—John T. Whistler.
South Dakota.—Charles H. Fitch.
Utah.—George L. Swendsen.
Washington.—Theron A. Noble.
Wyoming.—H. N. Savage, northern portion; J. H. Quinton, southern portion.

REPORT OF THE CONFERENCE.

ATTENDANCE AT EL PASO CONFERENCE.

The following members of the Reclamation Service were present at the conference at El Paso, November 14 to 18, 1904:

Bien, Morris, engineer and legal adviser.
Chandler, A. E., State engineer for Nevada.
Chandler, Elwyn F., State engineer for North Dakota.
Darton, N. H., geologist.
Fellows, A. L., district engineer.
Hall, B. M., supervising engineer.
Hewitt, C. E., assistant engineer.
Lee, W. T., assistant geologist.
Lippincott, J. B., supervising engineer.
Matthes, G. H., engineer.
Means, Thomas H., engineer of soils.
Mendenhall, W. C., geologist.
Newell, F. H., chief engineer.
Perkins, E. T., engineer.
Reed, W. M., engineer.
Rhead, J. L., assistant geologist.
Savage, H. N., supervising engineer.
Slichter, C. S., consulting engineer.
Storrs, H. A., electrical engineer.
Taylor, Thomas U., hydrographer.

In addition to these there were in attendance at several of the meetings the following: Gifford Pinchot, chief, and E. A. Sterling, assistant chief, Bureau of Forestry; C. W. Dorsey and J. G. Holmes, of Bureau of Soils, Department of Agriculture; Senator W. A. Clark, of Montana; Senator F. G. Newlands, of Nevada; Governor George C. Pardee, of California; Governor J. T. Morrison, of Idaho; Governor Ahumada, of Jalisco, Mexico; A. J. McCune, ex-State engineer of Colorado; M. K. H. Bakhati, engineer of the Nile, Egypt; F. C. Finkle, consulting engineer, and many other prominent persons.

MINUTES OF EL PASO CONFERENCE.

November 14.—The engineers of the Reclamation Service convened at the Angelus Hotel, El Paso, Tex., at 8.30 a. m. A brief address was made by the chief engineer on the operations of the past year and plans for the future. Administrative details were discussed informally and a number of short papers presented.

In the afternoon the session was resumed and a delegation of citizens from Oklahoma was received and the prospects of early construction of reclamation projects in that Territory were discussed. A brief statement was made by Mr. M. K. H. Bakhati concerning

irrigation in Egypt. In the evening a conference was held with Hon. Francis G. Newlands and with various delegates from the arid States.

November 15.—A conference was held with Representatives Smith and Stephens of Texas, and the situation on the Rio Grande was discussed by B. M. Hall and Thomas U. Taylor. Adjournment was had to the general meeting of the Twelfth Irrigation Congress. At noon the engineers met Governor George C. Pardee, of California.

In the afternoon the engineers attended the general meeting of the Irrigation Congress, addresses being made by the chairmen of the various sections.

November 16.—The engineers met in the county court room, various papers being presented and discussed. Among these were the following: Reclamation in the State of Washington, by H. N. Savage, supervising engineer; Construction Work in Oklahoma, by Gerard H. Matthes, district engineer; Underground Waters of Southern California, by W. C. Mendenhall, and discussion by F. C. Finkle; River Floods and Water Resources of North Dakota, by E. F. Chandler.

In the afternoon the session was resumed at 2 p. m., and a general discussion on a State irrigation code was opened by Morris Bien. This was followed by a paper on the Klamath project in Oregon and California, by J. B. Lippincott. A short address was given by Governor Ahumada, of Jalisco. In the evening delegations from New Mexico, Utah, and Arizona were received and the reclamation projects in each important locality were discussed.

November 17.—A general public meeting was held in the large convention hall, papers being read by H. A. Storrs on Irrigation Development in North Dakota; by Thomas U. Taylor on Texas; and by Robert Gayol, of the City of Mexico. The principal discussion was on the paper by B. M. Hall on Water Storage on the Rio Grande. This was followed by a brief paper by Charles S. Slichter on the Underflow of the Rio Grande.

At the afternoon session papers were read by Thomas H. Means on the Necessity of Draining Irrigated Lands; by A. L. Fellows on Estimates of Tunnel Work; and by H. A. Storrs on Sources of Power for Pumping Plants.

The conference then adjourned to meet at Washington, D. C., at the call of the chief engineer.

MINUTES OF WASHINGTON CONFERENCE.

The following are minutes of the various meetings held during the conference of the engineers of the Reclamation Service at Washington from January 2 to 14, 1905. The results will be found in the reports of the various committees (pp. 160–215).

January 2.—Reception by the President at the White House.

January 3.—General meeting of engineers and hydrographers at the Geological Survey Building. This meeting was for the purpose of organization and announcement of plans for the succeeding two weeks. The following members of the hydrographic branch were either present at that time or reported later in the conference:

Babb, Cyrus C., engineer.
Baker, S. K., hydrographic aid.
Barrows, H. K., engineer.
Bien, Morris, engineer and legal adviser.
Blanchard, C. J., statistician.
Bliss, George H., assistant engineer.
Bolster, R. H., assistant engineer.
Branch, L. V., assistant engineer.
Burnham, W. W., hydrographic aid.
Cass, F. H., traffic agent.
Clapp, S. K., assistant engineer.
Comstock, H. D., engineering aid.
Covert, C. C., assistant engineer.
Darton, N. H., geologist.
Davis, A. P., assistant chief engineer.
Eames, H. L., engineering aid.
Fellows, A. L., engineer.
Field, J. E., engineer.
Fitch, C. H., engineer.
Follansbee, R., assistant engineer.
Fuller, M. L., geologist.
Giles, J. M., assistant engineer.
Grover, N. C., engineer.
Hall, M. R., hydrographer.
Hall, W. E., engineering aid.
Hanna, F. W., assistant engineer.
Harley, G. F., engineering aid.
Hawley, R. W., assistant engineer.
Hill, Louis C., supervising engineer.
Horton, A. H., engineer.
Horton, R. E., hydrographer.
Hoyt, J. C., computer.
Johnson, Edward, jr., engineer.
Kastl, A. E., engineer.
Leighton, M. O., hydrographer.
Lemenager, H. V., draftsman.
Lewis, S. J., assistant engineer.
Lippincott, J. B., supervising engineer.
McConnell, I. W., engineer.
Means, Thomas H., engineer of soils.
Morse, H. M., engineering aid.
Murphy, E. C., engineer.
Newell, F. H., chief engineer.
Noble, T. A., engineer.
Olberg, C. R., assistant engineer.
Parker, H. N., assistant hydrographer.
Paul, E. G., engineer.
Perkins, E. T., engineer.
Prall, C. T., engineer.
Pressey, F. E., engineer.
Quinton, J. H., consulting engineer.
Richardson, G. B., assistant geologist.
Robbins, S. B., engineer.
Ross, D. W., engineer.
Sanders, W. H., consulting engineer.
Savage, H. N., supervising engineer.
Schlecht, W. W., assistant engineer.
Slichter, Chas S., consulting engineer.
Stabler, Herman, engineering aid.
Steward, W. G., assistant engineer.
Storrs, H. A., electrical engineer.
Taylor, L. H., engineer.
Taylor, Thos. U., hydrographer.
Tillinghast, F. H., assistant engineer.
Walter, R. F., engineer.
Webster, N. E., jr., accountant.
White, T. B., assistant engineer.

The chief engineer appointed the following committees:

Personnel and assignments.—Davis, Fitch, Savage.

Water laws and forms of water users' associations.—Bien, Ross, Chandler, Field, Noble.

Duty of water, alkali, and drainage.—Means, Sanders, Leighton, Slichter.

Methods of reconnaissance and survey.—Savage, Wisner, Fitch, Noble, Lippincott.

Standard plans and specifications.—Quinton, Wisner, Davis, L. H. Taylor.

Costs and results.—L. H. Taylor, Fellows, Webster, Olberg, McConnell, Paul.

Cement and concrete.—Wisner, Duryee, Kastl, Eckel, Wells, McConnell.

Electric power development and pumping.—Ensign, Storrs, Sanders, L. H. Taylor, Horton.

Stream measurements.—Grover, Murphy, Hinderlider, T. U. Taylor, Horton.

Auditing.—Fitch, Perkins, Paul.

Organization.—Kastl, Wells, Lippincott, Ross, Walter, Sanders, Ensign, Quinton, McConnell.

Transportation.—Davis, Bien, Storrs, Cass, Perkins.

Fiscal.—Newell, Davis, Webster.

The chief engineer directed that the committees confer immediately and prepare reports to be presented to the conference, and finally come to conclusions and make definite recommendations with reference to the various features of the work which they were appointed to consider.

During the remainder of the day the engineers attended the American Forest Congress.

January 4.—The day was set apart for conferences of standing committees for consideration of the matters assigned and the methods of presenting the same to the general conference.

In the afternoon the section of costs and results took up the discussion of methods of preparing engineering estimates of the actual cost of work accomplished and the consideration of the details of the original records for the purpose of obtaining the facts. The report of this committee will be found on pages 162–173.

January 5.—Mr. Asa Phillips, engineer of the District of Columbia sewage department, described the work which had been carried on in connection with the construction and maintenance of the trunk sewer for the city of Washington. Mr. Phillips exhibited detailed plans of the pumping station and discussed some of the interesting problems concerning the great work. The subjects of cement and concrete construction and of pumping were also discussed, great interest being manifested in them.

A conference of the committee on water laws and forms of water users' associations was held, but was not concluded at the expiration of the period allotted.

A conference was held with Messrs. Person, Ray, and Swift, auditor and assistant auditors of the Department of the Interior. Mr. Person and associates explained the distinction made between suspensions and disallowances, and advised concerning the best methods of procedure in each case. Further information was given with reference to contracts, railroad freights, and passenger rates.

A brief address was also made by Representative J. M. Dixon, of Montana, who spoke of the great importance to his State of the work of the Reclamation Service.

Representative Robert W. Bonynge, of Colorado, also met the

engineers, and Mr. Howard Elliott, chief engineer of the Northern Pacific Railroad, called with Mr. Thomas Cooper, land commissioner.

In the section meetings the principal topics discussed were the limits of accuracy in reporting discharge measurements, in constructing rating tables, and in applying gage heights. This subject was introduced by Mr. R. E. Horton, of New York.

Another matter carefully considered was that of methods of counting seconds and revolutions in making low-water measurements. The discussion was opened by Mr. John C. Hoyt, chief computer.

At 3 p. m. the conference adjourned to attend the session of the American Forest Congress.

January 6.—The morning session was given over largely to the discussion of the subject of transportation of materials and laborers in connection with the great irrigation works now under way or proposed.

An important subject of discussion was "Contracts," with a view to simplifying present methods of advertising to secure the largest publicity and the greatest number of bids for Government contracts. There was a meeting of hydrographers at 11 a. m. to listen to a discussion of "Bench marks" by Mr. E. Johnson, jr., hydrographer in charge of the Mississippi River district. This meeting was continued over into the afternoon, when it was addressed by Mr. E. C. Murphy, inspector of stream gaging, on the subject of "Equipment for cable stations."

At the afternoon session Mr. C. C. Babb discussed the Milk River project in Montana and its engineering complications.

January 7.—The morning session was given over principally to the discussion of the work of the service in Snake River Valley, in Idaho. The entire Idaho delegation, composed of Senators Dubois and Heyburn and Representative French, were present and addressed the engineers.

District Engineer Ross, who is in charge of the Government's work in that State, briefly outlined the plans for reclamation, explaining in detail the location and extent of the irrigable lands and the character of hydraulic works required.

Following Mr. Ross's discussion, Senator Dubois spoke briefly on the subject of irrigation development in Idaho.

Senator Heyburn explained that, although a resident of the Panhandle of the northern part of Idaho, which has an abundant rainfall, he was none the less deeply interested in the material development of the southern, or arid, portion of his State. He said he believed that the plans of the Reclamation Service as outlined are safe, and had no patience with the complaints of those not informed as to the character of these works who criticised the engineers for proceeding slowly.

Representative French, of Idaho, called attention to the extreme need of modification of our present homestead laws where they pertain to areas embraced in the Government's projects.

The morning session was concluded by an interesting address by Mr. H. E. Williams, of the United States Weather Bureau, representing Mr. Willis L. Moore, who could not be present.

In the afternoon conference the hydrographers were addressed by E. C. Murphy, inspector of gaging stations, on the subject of "Cost of stream gaging,"[a] and Mr. J. C. Hoyt, computer, on the "Study of data by local men."

District Engineer L. H. Taylor, in charge of Nevada work, addressed the conference on the subject of the Truckee-Carson project and its recent developments.

S. B. Robbins, engineer, described the plans for the Sun River project, Montana. This contemplates the irrigation of bench lands lying between Sun and Teton rivers.

January 9.—The morning was devoted to a discussion of the Belle Fourche project, South Dakota, led by Raymond F. Walter. Senators Kittredge and Gamble and Congressmen Burke and Martin took part. The Government will probably begin actual construction by the 1st of next April. The Secretary of the Interior has set aside the sum of $2,100,000 for the construction of this work. The plans and detailed estimates have been prepared and finally approved by the consulting board of engineers.

The committee on duty of water, alkali, and drainage called attention to the importance of these points as viewed from the past history of irrigated lands in the West.

The chief engineer, in executive session with the supervising, consulting, and district engineers and experts, discussed the broad principles of construction and cost, and the relations which the coordinate branches of the service bear to each other.

At the afternoon meeting of the hydrographers the chief engineer spoke of the Bureau of Forestry and called attention to the intimate relations its work bears to that of the Survey. Computer Hoyt discussed the work of the computing section.

The committee on cement and concrete took up the subject of the materials which enter so largely into the construction of the Government's great dams and headworks. An interesting feature of the discussion was a description of the cement mill erected by the Government to manufacture 200,000 barrels of cement for the Roosevelt dam, in Arizona, which is to be one of the highest dams in the world.

January 10.—T. A. Noble, in charge of work in Washington State, spoke of the Big Bend irrigation project, saying that owing to the

[a] See pp. 121-123.

enormous area involved, and the great cost, it has not been found practicable to proceed with its construction.

Supervising Engineer J. B. Lippincott discussed the Klamath irrigation project.

Mr. Lippincott also told of the project known as the Yuma on the Colorado River.

By invitation of Chairman Mondell, the chief engineer and a number of supervising and constructing engineers of the Reclamation Service met the members of the House Committee on Irrigation on this date, the principal topic of discussion being the Klamath project in California and Oregon. Mr. J. B. Lippincott described the important features of the project, which involves the irrigation of 300,000 acres, about half of which is Government land. The Klamath project possesses many unusual features of engineering, among which are the lowering of several lakes and the drying up of others. Two of these lakes are interstate bodies of water and both are navigable. It is necessary to have a special act of Congress to divert these waters, as such diversion will affect their navigability.

In the afternoon the supervising engineers met the committee and discussed the reclamation work for the past season.

The committee was desirous of securing all the information obtainable concerning the present status of the work, and took advantage of the opportunity of receiving the facts from the engineers in direct charge.

The adjourned conference with the committee on water laws and forms of water users' associations was continued.

January 11.—Thomas H. Means, engineer of soils, presided at the conference. The topic of discussion was the duty of water, or the amount of water required to properly irrigate the lands under project. Under the terms of the irrigation act it is necessary for the Reclamation Service to determine as closely as possible the amount of water which may be allowed per acre, and as this varies with the character of the soil and the actual demands of the various crops, it is usually a matter of dispute even among engineers who have had the best opportunity to precisely determine the question. A set of rules bearing on the subject were finally adopted at the conference.[a]

A conference was held with the committee on standard plans and specifications.[b]

Shortly after noon the engineers called on President Roosevelt, to whom they were introduced by Director Walcott and Chief Engineer Newell. The President said:

"No measure of public importance except the Panama Canal is of

[a] See committee report, pp. 173–177. [b] See committee report, pp. 189–206.

deeper interest to me than the work of the Reclamation Service. I am greatly pleased to enjoy this opportunity of meeting with the engineers who are engaged upon this very important work of developing our country's resources."

Those who called on the President were:

Cyrus C. Babb, engineer; S. K. Baker, hydrographic aid; H. K. Barrows, engineer; Morris Bien, engineer and legal adviser; C. J. Blanchard; F. H. Cass, traffic agent; C. C. Covert, assistant engineer; A. P. Davis, assistant chief; A. L. Fellows, engineer; J. E. Field, engineer; J. M. Giles, assistant engineer; N. C. Grover, engineer; M. R. Hall, hydrographer; R. W. Hawley, assistant engineer; R. E. Horton, hydrographer; Edward Johnson, jr., engineer; A. E. Kastl, engineer; M. O. Leighton, hydrographer; H. V. Leménager, draftsman; J. B. Lippincott, supervising engineer; I. W. McConnell, engineer; Thomas H. Means, engineer of soils; F. H. Newell, chief engineer; T. A. Noble, engineer; C. R. Olberg, assistant engineer; E. T. Perkins, engineer; C. T. Prall, engineer; J. H. Quinton, consulting engineer; S. B. Robbins, engineer; D. W. Ross, engineer; H. N. Savage, supervising engineer; W. W. Schlecht, assistant engineer; H. A. Storrs, electrical engineer; L. H. Taylor, engineer; R. F. Walter, engineer, and N. E. Webster, jr.

January 12.—Mr. John E. Field, engineer in charge of the North Platte investigation in Wyoming and Nebraska, discussed at length the Pathfinder project. Members of the Nebraska delegation in Congress—Senator Dietrich, Representatives Hitchcock, McCarthy, Norris, and Hinshaw, former Senator Manderson, and Mr. B. A. Fowler, of Arizona—were present.

Following Mr. Field's address Supervising Engineer H. N. Savage gave a description of the Shoshone project in Big Horn County, Wyo.

Later a conference was held with the committee on reconnaissance and survey,[a] and another with the committee on transportation.

January 13-14.—Mr. J. J. Hill, president of the Great Northern Railroad, addressed the engineers, speaking of the great work of irrigation, its progress under individual efforts, and its splendid future under the irrigation law. He promised his hearty cooperation in the Government work in the territory tributary to his lines.

By invitation of Senator Bard, chairman of the Senate Committee on Irrigation, the chief engineer and principal supervising and constructing engineers of the Reclamation Service appeared before the committee and discussed several bills of importance to the reclamation work. Chief Engineer Newell explained the exigency which has arisen necessitating the proposed legislation, the discussion being taken up by Supervising Engineer Lippincott and Mr. Bien, legal adviser.

[a] See committee report, pp. 187-189.

ADDRESS BY THE CHIEF ENGINEER AT EL PASO.

At 8.30 a. m. on Monday, November 14, the chief engineer called the conference to order at El Paso, Tex., and made an informal address upon the organization of the Reclamation Service and the principal changes that had taken place since the meeting at Ogden. An informal discussion followed, questions being answered and the details referred to committees. The principal topics of discussion are given in the following pages, various details being amplified as the result of subsequent proceedings.

PURPOSE OF THE MEETING.

The principal engineers of the Reclamation Service have been brought together for the second time in a general meeting for the purpose of discussing matters of interest to all and of strengthening the work through a larger comprehension of its scope and an interchange of ideas. In the two and one-half years which have elapsed since the reclamation act went into effect the Reclamation Service has grown rapidly and has approached nearer the maturity of a permanent organization.

The report of the first conference, held at Ogden, has been printed as Water-Supply and Irrigation Paper No. 93, and has been distributed to all members of the Reclamation Service. This has served to bring to the attention of all of the men the relation of one part of the work to another and has served in many ways as a text-book or manual of instruction on many points that have needed explanation. It is proposed to embody in a similar pamphlet the results of the second conference and to insert discussions of details supplementing those given in paper No. 93.

In the general discussions which are to follow it is hoped that the various engineers present will bring forward the results of their experience during the past year, show what improvements in methods have been successfully tried, and point out difficulties which may be avoided by others. In particular, attention should be given to all matters of economy, both large and small. It must be continually borne in mind that although the Reclamation Service is a part of the administrative branch of the Government, yet it must at the same time be a strictly business organization and display sound financial judgment in seeing that there is received for every expenditure the equivalent value.

It is not sufficient in the operations carried on under the reclamation act to merely expend the reclamation fund for good works, but these must be financially successful and must return to the Treasury their original cost. In this respect our work differs from that of almost every other operation under governmental auspices, in that, while we

do not consider interest and profit, yet we must get back the investment within relatively few years. The fund must be preserved for future use again and again in the many large projects which are now known to be feasible.

The definition of an American engineer is a man who, for $1, can produce results that another man can for $2. This idea must be kept prominently in the minds of all of our men. Advancement in the Reclamation Service, as well as standing in the judgment of the world at large, is dependent upon each man showing that he can and is producing substantial and permanent results at a relatively small outlay of time and money. As employees of the Government we have no excuse for not doing good work and completing permanent structures; but the credit which is properly attached to these is largely modified by considerations of their cost. Extravagance can not be tolerated. At the same time it is understood that the Government is not parsimonious nor niggardly, but that the higher officials and the public require that the returns shall be commensurate with the outlay.

There is one direction in which in the future larger expenditures should be made, and this is in the matter of complete records of expenditures and of costs. This general matter of bookkeeping and cost keeping should be discussed very thoroughly at this conference, and ideas developed along the most effective lines of recording essential facts.[a]

It is necessary to know not merely how much has been paid out for various purposes, but also to record from time to time the facts which will enable careful estimates to be prepared of the exact unit cost of each class of work or kind of operation. These facts are needed, not merely to show what has been accomplished, but for guidance in preparing future estimates.

The reclamation act was signed by the President on June 17, 1902, or twenty-nine months ago. During that time work has been energetically pushed in all parts of the arid region in the survey, examination, and beginning of large works. The engineering corps, which has been gradually created to meet the needs of the service, consists of well-trained and experienced men, selected through the Civil Service Commission. The gathering here is for the purpose of bringing representative men together and of affording opportunity for the principal engineers of the Reclamation Service to meet with each other and with citizens and statesmen interested in the future development of the arid region.

The foundation of success is in securing good men and in giving them every opportunity and encouragement to do good work. The

[a] See report of committee on costs and results, pp. 162–173.

occasional bringing together of the principal men should serve as a means of stimulating all to effective effort, and this stimulus should be transmitted to the men in the field who can not be conveniently brought together at a conference of this kind. It is incumbent upon each of the engineers not only to assist in the conference, but to take back to his assistants or subordinates the good results of contact with men in similar lines of work.

PERSONNEL OF THE SERVICE.

During the past year a considerable number of new men have been added to the Reclamation Service, most of these being young assistants, men fresh from college with good education, ambitious, and eager to enter upon active work. These young men should be given every reasonable opportunity to obtain breadth of experience, as from among them are to come the strong engineers of the future. Much of the success in constructing and operating great irrigation works rests upon giving these men a thoroughly practical training in details.

There has also been added a number of more experienced men and a few constructing engineers of large reputation. From time to time other constructing engineers will be added, these men being selected, as is the case of all others, through competitive civil-service examination, in which, however, experience is given greater weight than in the case of the younger men.

ORGANIZATION.

Next in importance to the actual character of the men engaged in the Reclamation Service is that of the organization or relation of the various men to each other. This subject is one which has been frequently discussed, and, while in a broad way the details have been outlined, yet there are many important matters for further discussion. A committee on organization, to be designated in the future, will probably make a report as to the present views on the subject.

ENGINEERS AND ASSISTANTS.

The engineers, assistants, and aids of our various classes or grades are, as a rule, systematically grouped in field parties, and the organization should be such that no confusion can arise as to the responsibility of each man. Great care must be taken in selecting chiefs of field parties to see that each has an adequate force of assistants, and that tact and discretion is displayed by the chiefs of independent parties in placing the assistants where they will be most effective. To a certain extent the reputation of the entire Service rests upon the

parties operating more or less independently away from central offices.

DISTRICT ENGINEERS.

The district engineers, located at central or convenient points in the district, are responsible for all of the engineers and assistants under them, and as the work develops should have their headquarters at or near the point where most men are employed and where a general oversight of the work can be most expeditiously had. District offices can be rented when in or near towns or cities, but during the past year there has been a tendency to move the district offices to the point of construction if ordinary facilities for mail and supplies can be had there.

FIELD ASSISTANTS.

The conditions of employment in the Reclamation Service are discussed in Water-Supply Paper No. 93, pages 24–35, and details relating to subsistence are shown on page 85. The underlying law and theory has, however, not been fully presented, and it is essential for a full comprehension of the subject to go back to the fundamental principles.

The reclamation act does not bear directly upon the matter of employment and subsistence of men, but by inference this is implied in the second section, authorizing and directing the Secretary of the Interior to make investigations and surveys and to give estimates of cost of all contemplated works. This, of course, necessitates the employment of a large number of men, and, as in the case of all surveys in distant regions, requires that certain equipment, including subsistence, shall be furnished. Since, therefore, the reclamation act does not define these matters, it is necessary for further details to consider the general laws, practices, and rulings governing similar operations of the Government, and reference should be made to the Revised Statutes and more recent acts of Congress and to decisions of the Comptroller as well as those of other law officers of the Government.

As illustrated by current practices, there are numerous ways in which employment is had. These may be conveniently classified as follows:

(*a*) Appointment by the Secretary after competitive civil-service examination to permanent or statutory places.

(*b*) Appointment by the Secretary after competitive civil-service examination to temporary positions.

(*c*) Employment by subordinate officials as required by exigencies.

At the present time there are no appointments under the first

category, as the reclamation act and subsequent acts of Congress have not created any statutory places or salaries; hence all appointments are officially designated as "temporary" to distinguish them from appointments which are made to fill definite positions. This matter is explained in Water-Supply Paper No. 93, page 27.

The regular employees of the Reclamation Service fall under the second category, viz, those appointed by the Secretary after competitive civil-service examination. The various grades and classes are briefly described in Water-Supply Paper No. 93, page 36.

The occasional or field employees are hired for the time being by engineers in the field as exigency arises, under the general authority given by the Secretary to employ field assistants. Their places should be filled as soon as possible through certification from the Civil Service Commission.

In the employment of field assistants care must be taken to distinctly state and record the essential facts as to terms of employment, transportation, and subsistence, and to ascertain that these terms are in accordance with the law and authority given.

Each person employed should be furnished with a written statement covering all of these terms, and a copy should be forwarded immediately to the office of the chief engineer for record there. This statement should give the dates of the letters of authority for such employment and state the rate per day or month, the fact whether transportation is to be furnished, and particularly the terms of subsistence, the date of service, and the times when subsistence is to be begun or discontinued.

SUBSISTENCE.

The general conditions relating to subsistence of all employees are given on page 85 of Water-Supply Paper No. 93. Under the head of subsistence are included the necessary expenditures made for furnishing food and suitable shelter or space for sleeping accommodations. Where men are employed, as the majority in the Reclamation Service are, on work remote from human habitations, provision must be made, not merely for transporting the men to these remote localities, but for furnishing them food and shelter while there. Two divergent and apparently contradictory opinions have been presented concerning the legal basis for furnishing subsistence. On the one hand, it has been held that field subsistence is furnished, not as a perquisite or emolument, but solely as a necessity in facilitating work in the same way that horses, wagons, and tools are provided. On the other hand, arguments have been presented to show that the legal basis is to be found in the fact that subsistence in the field is a part of the compensation paid for services. This latter is probably the correct view.

KINDS OF SUBSISTENCE.

Subsistence may be considered as being furnished under one of several heads:

(*a*) Subsistence in kind; that is to say, the issuance of rations to the members of a party in camp, and their preparation by persons employed for this purpose.

(*b*) Repayment for actual and necessary expenses incurred when traveling, when supported by vouchers executed in the required form.

(*c*) Payment of a per diem allowance in lieu of traveling expenses or of subsistence, this allowance being sufficient to cover the usual cost of such subsistence.

LAWS GOVERNING SUBSISTENCE.

The fundamental act governing subsistence is that of March 3, 1875 (18 Stat. L., 452), as follows:

> That hereafter only actual traveling expenses shall be allowed to any person holding employment or appointment under the United States * * * and all allowances for mileage and transportation in excess of the amount actually paid * * * are hereby declared illegal; and no credit shall be allowed to any of the disbursing officers of the United States for payment or allowances in violation of this provision.

In a letter from the Comptroller of the Treasury, dated April 11, 1905, the following statement has been made:

> Relative to the field men of the Reclamation Service and the payment of actual traveling expenses incurred, or a per diem in lieu of their subsistence and lodging, it is usual in all branches of the Government service to pay field men either their actual and necessary traveling expenses (act of March 3, 1875, 18 Stat. L., 452) up to the maximum departmental limit, if actually incurred when traveling in the field, or a per diem as commuted when such expenses are commutable and commuted under the law.
>
> Government employees are not in a traveling status when either at their homes, domiciles, or at their stations. A station is a place the opposite of the field. Stationed men, when paid from a lump sum, have the fact taken into consideration in fixing their compensation, that while at their official stations they are not in a traveling status, and are not allowed traveling expenses or a commutation in lieu thereof.
>
> Where the duties of a person in the Reclamation Service require him to be in a particular place for a long period of time performing what is usually known as station work, such person can not be considered as in the field in the absence of being officially stationed at some other place.

LOCATION AS AFFECTING SUBSISTENCE.

The question of subsistence is evidently dependent upon the location of the employee. Four distinct conditions appear to be contemplated by the law and regulations:

(*a*) Home.

(*b*) Station.

(*c*) Field.

(*d*) Traveling.

Subsistence at home.—When an employee is at home no subsistence is furnished. The question, therefore, as to what constitutes a home is one which has to be considered. In the case of a married man the test is as to the location of his family. If a man is so located that his wife is with him, he is assumed to be at home, even though this home is located in a camp. As a rule no quarters or subsistence are allowed under these conditions.

Subsistence at station.—A station is a definite place or location where a man or body of men is habitually employed, such, for example, as at a local office of the Reclamation Service or at the point of construction of a large work.

The local offices, as a rule, are in or near towns, and subsistence is not furnished. On construction work, however, quarters are, as a rule, provided, as is customary in such cases, as there are no lodging places near by and the work is facilitated by having the men live close at hand. In other words, lodging is provided for the reason that without it the work would suffer, because the men could not otherwise live in the vicinity. Food is not furnished at stations, excepting during the preliminary stages of establishing a construction camp, when the party is virtually on a field basis and has not definitely assumed a permanent position. It is necessary to draw an arbitrary line between the field condition, where the location of individuals and of parties is unsettled, and the comparatively permanent station, when facilities for procuring food have been established.

Subsistence in the field.—Field location, as such, is distinguished by the fact that operations are not at any one particular place. The equipment is designed for mobility and the operations are carried forward, moving habitually from place to place, generally in unsettled regions. The fact that the party must be continually on the move and that there is no way of effectively carrying forward the work without furnishing lodging and food necessitates furnishing these. This condition is well recognized in all surveys and explorations, and individuals or corporations carrying on such work habitually furnish the means of transportation, tents, if needed, and all of the usual food materials in the raw state, together with a cook to prepare and serve the food. Subsistence is thus furnished as a matter of course, and it practically goes without saying that when an assistant is employed on a surveying party he is furnished with the necessary transportation, equipment, and food. This is not generally recognized as an emolument or perquisite, but as a necessary prerequisite to carrying on the work.

Any gain to the individual in the reduced cost of living is con-

sidered as being offset by the arduous labor and exposure of outdoor life.

Subsistence when traveling.—In the ordinary course of travel subsistence is obtained in an entirely distinct manner from the usual methods in the field work. A person traveling can rarely be furnished with crude or raw food materials and with implements for cooking it. As a rule, lodging is obtained at hotels or public houses and food at restaurants or lunch rooms. In this case payment must be made from day to day for meals and lodging, and the method recognized by law and custom is to refund these costs upon the presentation of the customary vouchers. Each person, as a rule, pays his own way and submits separate vouchers, while in the case of a field party being subsisted on rations, these are purchased by the chief of party and the individual does not keep separate account of the cost chargeable to him.

The laws and decisions applying to subsistence seem to be drawn with particular reference to traveling expenses, and it is believed that the act of March 3, 1875, relates wholly to this condition and not to field subsistence furnished to parties engaged in surveys. Under this view it is possible to reconcile the two distinct opinions above noted, and to regard allowance for subsistence as an emolument or perquisite to be covered by the appointment of each person. On the other hand, the subsistence furnished in the field may be considered, not as a perquisite, but as a necessary incident to the work in hand.

PER DIEM ALLOWANCES FOR TRAVELING EXPENSES.

Construing the act of March 3, 1875 (18 Stat. L., 452), the Comptroller has held that "the allowance to an officer whose compensation is fixed by law of a fixed sum in lieu of all expenses, exclusive of transportation and sleeping-car fare, is not authorized by law" (7 Comp. Dec., MS. 17). But in another instance it was held that "this act refers to actual traveling expenses, and does not prohibit the head of a department, having discretion to contract for the services of an employee, from agreeing with such an employee upon an amount to include compensation and all expenses." So, also, may the contract be for a fixed sum as compensation *and an amount per day as additional compensation when absent from headquarters.* If actual cost of transportation is given also, it should be clearly stated, as, for instance, "Actual cost of transportation, exclusive of sleeping- and parlor-car fares" (5 Comp. Dec., 107).

Under date of January 30, 1905, the Interstate Commerce Commission adopted an order "that on and after the 1st day of February, 1905, inspectors of safety appliances will be paid at the rate of $1,500 per annum, and in addition thereto will be allowed the sum of $4

per day, including Sundays and legal holidays, while away from home and actually on duty, etc." This order was adopted after the matter had been approved by the Comptroller.

It may, therefore, be possible to allow a per diem to the engineer and other traveling employees of this Service as additional compensation for each day, including Sundays and legal holidays, while on official duty away from their homes and headquarters. When such a per diem is authorized and allowed the engineer should not approve any claim for reimbursement for the expenses of official travel other than those for the actual cost of transportation, including regular fares for railroad, steamboat, and stage travel, inclusive of sleeping- and parlor-car fares and necessary livery hire. When the expense of steamboat travel is claimed it must be shown whether meals were included in the passage rate, and if so, the per diem will not be allowed.

In computing the per diem allowance fractions of a day should be disregarded. When travel or duty away from home begins before noon or ends after noon, the full per diem for that day should be allowed; when such travel or duty begins after noon or ends before noon, no per diem for that day should be allowed. The day and hour of beginning and ending travel or duty and any absence from or suspension of duty while away from home and headquarters should be plainly and fully stated in the employee's report.

No per diem should be allowed to an employee for days when at home or at his headquarters nor when at any camp or station of this Service where he is lodged and subsisted at a table or mess conducted for the employees of this Service. No per diem should be allowed while on annual leave or other absence from duty, whether at his home, headquarters, or elsewhere.

Should an employee be absent from his home and headquarters on official duty under circumstances not entitling him to a claim for per diem, as upon departure from his home or headquarters after noon of one day and return before noon of the day following, he will be entitled to reimbursement for his actual expenses upon submission of a voucher properly prepared showing the actual expense incurred, with subvouchers for the various items, according to regulations now in force.

PAPERS READ AT THE CONFERENCE.

PROPOSED STATE CODE OF WATER LAWS.

By Morris Bien.

INTRODUCTION.

The simplest form of regulation of the use of water is best exemplified by the present laws of the State of California. These declare the principles of priority and beneficial use and provide that claims to the use of water shall be recorded in the form of a notice of appropriation and shall be perfected by application to a beneficial use.

The form and theory of these laws has been developed by several of the States, which have followed in general the California laws and elaborated upon the methods established in that State.

The operation of these laws places no restraint upon appropriations of water. Formerly the courts, in passing upon the claims of the appropriators, having scanty information concerning the amount of water available for use, with no guide to the quantities which should be applied in the cultivation of crops, and confronted with the excessive claims of the parties, often adjudicated rights to the use of water many times in excess of the amount carried by the stream. During recent years, however, the knowledge obtained concerning the discharge of streams and the use of water has caused such decrees to become exceptional. Nevertheless, the need for a more careful regulation of the appropriation and use of water has been apparent for many years.

In 1890 the State of Wyoming enacted a code of water laws providing for a thorough supervision of the utilization of the water supply of the State through a State engineer and State board of control, who adjudicate rights to the use of water in the first instance, and division superintendents and water masters, who have immediate charge of the distribution of the water in the various water divisions.

Nebraska subsequently adopted a code of water laws substantially the same in principle as those of Wyoming. Idaho, Utah, and Nevada in 1903 adopted codes of water laws based upon those of

Wyoming, with, however, a number of important modifications dictated by the experience of Wyoming and the development of irrigation practice.

At the sessions of the legislatures of Oregon and Washington in 1903 the governors were directed to appoint commissions to prepare and submit drafts of a code of irrigation law.

At a joint session of the two commissions with the chief engineer and other members of the Reclamation Service, held last August, the fundamental principles of a modern irrigation code were discussed. There was also some consideration of the provisions which should be incorporated in such a code to facilitate the operations of the Federal Government in carrying on the work of constructing the irrigation systems contemplated by the act of Congress approved June 17, 1902 (32 Stat. L., 388), known as the "reclamation act."

As the conditions in the two States were similar, it was deemed advisable for the two commissions to work in harmony and to prepare codes which should be as nearly identical as the conditions would permit in the hope that by cooperation the commissions would be able to submit to the respective legislatures a code which should be an expression of the most advanced development of irrigation law.

At the conclusion of the joint session of the two commissions I was requested to prepare a draft of a code of water laws to form a basis of discussion by the commissions. The draft was prepared in a few weeks and widely distributed among those interested for comment and criticism.

A number of valuable comments and suggestions have been received, enabling me to formulate amendments which a subsequent careful study of the draft had shown to be advisable, besides suggesting important changes and improvements.

I desire particularly to express my obligations in this matter to Messrs. F. I. Dunbar, secretary of state of Oregon; A. E. Chandler, State engineer of Nevada; Clarence T. Johnston, State engineer of Wyoming; L. G. Carpenter, State engineer of Colorado; D. W. Ross, engineer in charge of the work of the Reclamation Service in Idaho, and T. A. Noble, engineer in charge of the work of the Reclamation Service in Washington.

PROVISIONS OF A WATER CODE.

A State code of water laws should provide for the appropriation, adjudication, and apportionment of the waters of the State, and divides itself naturally into four branches:

First. A declaration of the fundamental principles on which the right to use water shall be based.

Second. The adjudication of rights to the use of water claimed

under the laws previously in force, thus determining the unappropriated public waters.

Third. The regulation, control, and determination of the rights to water to be subsequently acquired.

Fourth. The regulation and control of the distribution of the water, rights to the use of which have been established.

In discussing these branches of the subject the important features of procedure in the code proposed for Oregon and Washington will be described.

Basic principles.—Under the first heading the fundamental principles are few and well established—namely, that all the waters within the limits of the State belong to the public and are subject to appropriation for beneficial use, except from sources of supply which are navigable; that the beneficial use of water shall be the basis, the measure, and the limit of the right; that the use of water is a public use, and private parties may exercise the right of eminent domain for the utilization thereof, and that water used for irrigation shall be appurtenant to the land on which it is used.

Adjudication of prior rights.—Under the second heading, providing for the adjudication of rights claimed under prior laws, it is now generally conceded that the final adjudication must be by the courts. The codes of the different States contemplate various forms of procedure. In the code proposed for Oregon and Washington a State engineer, appointed for six years by the governor, subject to confirmation by the Senate, is to make a complete hydrographic survey of a stream system, obtaining all the data necessary to determine the amount of water available and the rights of the parties entitled to the use of it. This material is turned over to the attorney-general of the State, who is required to enter suit promptly for the determination of the rights of all parties and to prosecute the same diligently to a conclusion. In all suits for the determination of the right to the use of the waters of any stream system all who claim the right to use such waters shall be made parties. In all suits involving the determination of water rights the attorney-general is required to intervene on behalf of the State if in the opinion of the State engineer the public interest requires it.

Establishment of new rights.—The third subject—namely, that of the regulation, control, and determination of rights to the use of water to be acquired—is placed in the hands of the State engineer. The procedure proposed is substantially the same as that adopted in the other States having a modern irrigation code, with some differences of detail.

The principal feature to be noticed is that before any work looking to the construction of an irrigation system is commenced, and after the State engineer has passed upon the form and substance

of the application, the intention to appropriate the water shall be published in a newspaper circulated in the community. After said publication the State engineer will approve the application if no valid objection is presented.

When the construction is completed, the works are to be inspected and approved by the State engineer, who will then determine their capacity, which will limit the amount of the appropriation. Afterwards, when the water is applied to a beneficial use, the State engineer will make a further inspection, whereupon he issues a license for the appropriation of the amount of water which has been applied to a beneficial use. A time limit is fixed for completion of construction and for beneficial use.

Distribution of water.—For the distribution of the water, which comes under the fourth branch, the States are divided by the law into four water divisions by drainage areas, each under the supervision of a water commissioner appointed by the supreme court of the State. The functions of these commissioners are the distribution of water under judicial decree or appropriation, and they may therefore be regarded as, in a sense, officials of the court. The four water commissioners, with the State engineer, constitute a board of water commissioners, of which the latter is president. The water commissioners each serve six years, their terms being so arranged that a new one is appointed every two years. This board has general supervision over the waters of the State.

The actual work of distributing the waters to those entitled to use them is done by water masters appointed by the water commissioners, with the approval of the State engineer. Each water master has charge of a water district set apart by the State engineer as found necessary from time to time. The operations of the water master are under the supervision of the water commissioner, and his acts are subject to appeal to the State engineer.

The cost of the water distribution is borne by the water users. The general expenses of the State engineer and the water commissioners are paid by the State. The greater part, if not all, of this expense will be returned to the State treasury by the fees collected by the State engineer and by the repayment of the cost of hydrographic surveys by the parties to the suits for adjudication.

The States and the Reclamation Service.—Special reference should also be made to the features of the draft relating to the work under the Federal reclamation act.

In order that the State may obtain the full benefit of this work and prevent serious interference with and perhaps the entire abandonment of the projects to be investigated, it is provided that the water supply for such projects shall be reserved from general appro-

priation until the investigations of the Reclamation Service shall determine the precise amount required for the project, the remainder being then released from such reservation.

It is also provided that State lands coming under such project shall be disposed of in harmony with the plans for the disposition of the lands of the United States, and that lands required by the Reclamation Service for irrigation works shall be transferred to the United States without charge.

In all future sales of State lands the conveyance is to reserve a right of way for ditches or canals constructed by authority of the United States.

The theory of these provisions is that the State regulates the appropriation of the water, exercising this power and holding the land in trust for the public, and that when the interests of the public are so directly involved as in these large irrigation projects, and when, further, there is no element of individual speculation or profit in the construction of the works, which are for the purpose of establishing the maximum number of homes on the land, it is the duty of every State to which the reclamation act is applicable to assist with every resource under its control.

Other provisions.—It will be of interest to review several of the other provisions of the draft.

Units of measurement are established: the cubic foot per second for the flow of water and the acre-foot for volume. The miner's inch is fixed as one-fiftieth of a cubic foot per second, unless a different ratio has been agreed upon by contract or established by actual measurement or use.

The amount of water which may be appropriated for irrigation is limited to 1 cubic foot per second for 70 acres or its equivalent.

While it is conceded that water used for irrigation must be appurtenant to the land, the fact must be recognized that conditions may arise to make it impracticable or uneconomical to continue to irrigate a particular tract. Provision is made so that the use of water may be severed from the land after application to the State engineer, due publication of notice of such intention, and approval by the State engineer. Similar provision is made for a change in the nature of the use to which the water is applied, or a change in the place of diversion, storage, or use.

The subject of seepage water is one that has given much trouble, and provision is made for the appropriation thereof in the same manner as other waters, with the requirement that the appropriator must pay reasonable charges for storage or carriage to the owners of the irrigation works from which it comes, provided that the seepage can be traced to such works beyond reasonable doubt.

All decisions of the State engineer or water commissioners affecting a substantial right are subject to appeal to the courts.

The commissions of the two States prepared drafts of codes upon substantially the principles herein outlined. The legislatures did not, however, adopt them, but passed certain laws governing the general procedure in regard to the adjudication of rights to the use of water.

In Oregon the office of State engineer was established and provision was made for a system of filing and adjudicating water rights.

An irrigation code without material change from that herein discussed was adopted early in 1905 by the legislatures of North Dakota, South Dakota, and Oklahoma.

During the legislative sessions of 1905 acts were passed in Colorado, Idaho, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming, providing for cooperation with the work of the United States in the construction of reclamation projects in regard to one or more of the following:

(*a*) Necessary water supply.
(*b*) Rights of way over State lands.
(*c*) Condemnation of private property.

HYDROGRAPHIC INVESTIGATIONS IN NEVADA.

By A. E. Chandler.

There are four important river systems in Nevada, three of which—Truckee, Carson, and Walker rivers—rise in the high Sierra of California and flow through fertile valleys to inland lakes in Nevada. In the high mountain country tributary to the three rivers there are numbers of beautiful, tree-fringed lakes. The largest of these are in the Truckee basin, Lake Tahoe, with its area of 195 square miles, being by far the greatest in size. The Truckee empties into Pyramid and Winnemucca lakes, the Carson into Carson Lake and Carson Sink, and the Walker into Walker Lake.

The fourth river of importance is the Humboldt, which has the distinction of being entirely a Nevada river. It rises in the high mountains in the extreme northeast corner of Nevada and flows in a general southwesterly direction for 350 miles to Humboldt Lake. Twice within the last fifty years the flood waters of the Humboldt have reached Carson Sink.

The lowest reaches of all four rivers vary but little in elevation—the lowest, Lake Winnemucca, possessing an altitude of 3,825 feet, and the highest, Humboldt and Carson lakes, 4,100 feet. It is worthy of note that the Truckee-Carson project now being constructed by the Reclamation Service will utilize the waters of the Truckee in

the Carson basin, and may carry the commingled waters of the two rivers to Lovelock Valley, the lowermost valley of the Humboldt basin. When it is added that it is practicable to connect the Walker with the Carson, the close proximity of the four streams in their lower basins must be apparent.

Besides the four rivers mentioned above there are several smaller rivers and a multiplicity of mountain streams. Salmon, Bruneau, and Owyhee rivers rise in the extreme northern part of Nevada and flow northerly into Snake River in Idaho. Virgin River rises in southwestern Utah and flows across the southeast corner of Nevada to join the Colorado. Muddy River has its source in springs on the Moapa Indian Reservation, in Lincoln County, Nev., and flows for 30 miles through the same country to its confluence with Virgin River. Quinn River and its tributary, Kings River, rise north of the Oregon line and flow southerly and westerly a distance of 80 miles, to sink in the Black Rock Desert of northwest Nevada.

Throughout the central portion of Nevada there are numerous high mountain valleys, the waters of which belong to none of the systems enumerated above. The small streams have their source in the snow-capped peaks of the neighborhood or in springs at the base of the range. The scattered mining camps make the produce of their valleys very valuable, and, as irrigation is absolutely necessary, all the water is utilized.

The first systematic stream measurements in Nevada were made by the United States Geological Survey on Truckee and Carson rivers from 1889 to 1892. Gaging stations were established by the same agency on Humboldt River in 1894 and have been continued to the present time. Measurements were also made at stations on Walker, Carson, and Truckee rivers during part of the year 1905.

The Congressional appropriations for hydrographic work made possible the establishment of a number of new stations in the basins of the four rivers in 1899–1900, and the scope of the work has been extending ever since. In 1903 the Nevada legislature created the office of State engineer and provided that among his duties should be the measurement of streams and ditches. In order to avoid duplication in work the United States Geological Survey has made the Nevada State engineer its district hydrographer, and all gaging stations are maintained according to Survey regulations.

At present there are maintained three gaging stations on the main Humboldt and one on each of three tributaries—North Fork, South Fork, and Pine Creek. There are four stations on the main Truckee, one on the inlet to Lake Winnemucca, and four on tributaries in California. On each of the two branches of Carson River, East and West forks, stations are maintained, and a

third is situated on the main Carson River below upper Carson Valley, in which the two forks converge. Permanent stations have also been established on East and West forks of Walker River, and on the main river at the lower end of Mason Valley, in which the two branches join.

In 1903 the State engineer was asked by the people of Muddy River Valley to report on a reservoir site existing immediately above the valley. The site is undoubtedly good, but the water supply is questionable. In order to intelligently report upon the matter a gaging station was established upon the river immediately above the reservoir site and has been maintained since January 1, 1904.

The small and scattered population of Nevada make the maintenance of good stations a very serious problem. It does not suffice to find the point which is the best physically for a station, but rather a habitation must first be found and then some point in the vicinity selected at which to establish a gage rod. At the majority of the stations the gage rod and cable from which measurements are made have to be separated by long distances, often one-half mile. For gage readers there is little choice; every type is engaged, from the small schoolboy to the uneducated but faithful Italian farmer. There are a number of important tributaries to Humboldt River on which it is desired to conduct a series of measurements, but on which no practicable station can be found within miles of a residence.

The following remarks will show the fluctuations and average discharge at a number of Nevada stations. The flow of the Truckee at Vista, at the lower end of the largest irrigation valley in the basin, has varied between 7,510 second-feet in May, 1890, and 61 second-feet in August, 1900. The mean annual discharge for the year 1891 and for the years 1900 to 1903, inclusive, was 571,446 acre-feet.

The station on the Humboldt at Oreana is immediately above the lowermost valley of the basin. In May, 1897, the flow was 3,047 second-feet and in October, 1903, but 8 second-feet. The mean annual flow for the period 1896 to 1903, inclusive, was 169,390 acre-feet. The station at Golconda, on the Humboldt, is about 100 miles above the one at Oreana. The records show that the fluctuations at Golconda were from 3,100 second-feet in May, 1897, to nothing in the fall months of a few years. The mean annual discharge for the and for the years 1900 to 1903, inclusive, was 571,446 acre-feet.

The station on South Fork of Humboldt River is about 6 miles above its confluence with the main river. In June, 1899, the flow was 1,370 second-feet and the stream is often dry in September. The mean annual discharge for the period 1897–1903, inclusive, was 130,057 acre-feet.

Carson River, at Empire, has varied from 6,278 second-feet in

May, 1890, to 15 second-feet in September, 1902–3. The mean annual discharge for the period 1901–1903, inclusive, was 323,547 acre-feet.

The present stations on Walker River and its branches were not established until late in 1902. The discharge for 1903 of the main river at Wabuska, Nev., was 122,888 acre-feet; of East Walker, near Yerington, Nev., 79,562 acre-feet; and of West Walker, near Coleville, Cal., 225,091 second-feet.

Besides the work at regular stations, miscellaneous measurements of mountain streams and ditches have been made during every summer since 1900. It is proposed to continue these measurements in the future with special reference to the determination of the return waters after irrigation and to the duty of water.

During the season 1903–4 a number of rainfall stations were maintained at points in the Sierra Nevada. These stations are now being cared for by the United States Weather Bureau. A series of such records will be of the utmost importance to those interested in irrigation, as it is to the mountains we must look for our water supply. Until these stations were established but few rainfall records were obtainable for the higher altitudes.

POWER ENGINEERING APPLIED TO IRRIGATION PROBLEMS.

By O. H. Ensign.

In a paper treating of the growth of the use of power applied to irrigation work some statement concerning the history of the development and transmission of power by electrical means will not be out of place.

BEGINNINGS OF POWER TRANSMISSION.

In 1893 there was started in Mill Creek Canyon, above Redlands, Cal., the first three-phase alternating-current power-transmission plant in the United States. This plant utilizes the waters of Mill Creek under a head of 530 feet, using impulse water wheels directly connected to three-phase generators. This was one of the first plants in which the water wheel was directly connected to the generator, and, while it was essentially crude as compared with later development, it has been in continuous service down to the present time; from it was built up a system of power transmission which now covers a territory 150 miles long by 50 miles wide, supplying power for all manner of uses; and from the possibilities demonstrated by it, confidence was created and similar transmission systems have sprung into existence all over the country. As a direct object lesson in irrigation it is probably one of the most interesting developments in the West.

Since the first plant was constructed the same company undertook and brought to a successful conclusion the installation of the first long-distance line in the world, transmitting power from Santa Ana Canyon, another stream of the San Bernardino Mountains, to the city of Los Angeles, 83 miles away; when constructed this line was nearly three times the length and carried three times the voltage of any existing system, being constructed for 33,000 volts.

From an operating standpoint, as well as any other, this system has been a perfect success from the very beginning, and within the last two years there has been constructed, also in Mill Creek Canyon, another power plant feeding into this transmission system, operating under a hydraulic head of 1,960 feet. This plant has been in operation for eighteen months without a shut down from any cause due to the plant, and when it is considered that this is the highest pressure under which a large water wheel is operating anywhere in the world, the results may be regarded as truly phenomenal. Since this high-head plant has been in operation a similar one in the northern part of the State has been started which has single units, developing 7,500 horsepower in a single jet under a 1,700-foot head.

Owing to the fact that the demands had grown beyond the immediate practicable development of further water power in this section there has been recently installed as an addition to this system a steam turbine plant which feeds into the same transmission lines and distributing systems formerly supplied by the water-power plants alone; this plant has been in entirely successful operation without interruption for nine months. There is also being constructed a plant of 20,000-horsepower transmission to tie into this system from an entirely different watershed 116 miles away.

We have here, then, in a single system, an example of the development of power transmission through all its phases. Still operating on the system, too, is the first three-phase induction motor, the first three-phase synchronous motor, the first large unit on extremely high heads, the first four-stage vertical steam turbine in the United States, and the first 33,000-volt line of the world to be successfully operated.

This little historical sketch is given because in this system are exemplified the possibilities of development of irrigation systems along similar lines, and because in it there is afforded an opportunity to study the development step by step and to profit by mistakes as well as by improvements.

IRRIGATION AND POWER TRANSMISSION.

The promoters of this system little dreamed when they started the small plant in 1893 that one of its greatest sources of revenue would come from pumping water for irrigation, but to-day the waters

which flow down the canyons of Mill Creek and Santa Ana River are made through this means to furnish power for pumping water from wells in sufficient quantity to irrigate a section of country nearly four times as great as that which the water from the streams themselves irrigates. There are 107 of these pumping plants, with 3,050 total motor horsepower.

EFFICIENCY OF TRANSMISSION SYSTEMS.

A common error into which laymen are often led is in regard to the all-around efficiency of a hydro-electric transmission pumping system as usually installed. Most of the pumps operated on this system are of the vertical-shaft, centrifugal type, placed at the bottom of a shaft whose depth corresponds to the original level of the water plane. The pump is equipped with a suction pipe lowered into a driven well and supplying water through a discharge pipe to the surface of the ground or reservoir or perhaps to an elevation some distance beyond the location of the well. Taking the average of these conditions, the water horsepower to be created in the pumped water delivered to the irrigation ditch will not, as a rule, exceed 22½ per cent of the all-around efficiency from the water on the water wheels, and will often fall below that figure. On the other hand, a system could be built up for a special purpose, with short transmission in large units, whose efficiency would be as high as 32 per cent; and, according to the claims of certain manufacturers, in a system where the pumping plants required high-lift pumps, as high as 42 per cent.

The above efficiencies are all based on the use of the centrifugal pump, and it does not appear that with the average condition of the water which would be used for irrigation it would be at all practicable in considering any large irrigation project in which pumping was the main feature to use anything but a centrifugal pump. The maintenance account on plunger pumps, cylinders, valves, etc., where water carried mud and silt, would be so great as to make operating costs excessive, and, where motors are to be used, gears and the wear and annoyance, as well as the extra care for the whole device, would largely operate to make their serious consideration a matter of doubt.

The efficiency of the centrifugal pump has been increased to such an extent in the last few years that serious consideration of the plunger type of pump is unnecessary.

On the California system discussed, besides the style of pumps mentioned above, there are deep wells of the plunger type, systems of pumping from a large number of wells by means of compressed air, low-lift centrifugals operating out of streams or canals, and almost every other conceivable device for lifting water to which electric

motors could be attached. But the methods first referred to seem to be the most practical.

HEIGHT OF LIFTS.

Over a great section of this country the water is being lifted to a height of nearly 100 feet, and in some places more than that, but the large number of plants lift the water to such a height as would come within the limit of a single centrifugal pump. Since the beginning of the construction of this system great advance has been made in the construction of the impulse water wheel, and it is the belief of the writer that there will be seen here water wheels of the highest efficiency operated anywhere in the world, and not far from them wheels of a type which have now become obsolete and are being changed to the new types. All of the wheels are of the impulse type, as the lowest head of any of the plants is 480 feet.

USE OF STEAM TURBINES.

In the recent development which has occurred along the line of power generated by steam, the steam turbine has demonstrated its reliability, and its rapid introduction has convinced both investor and engineer of its practical adaptability to the problems of generating electric power. Along with the development of the steam turbine has come the development of the superheater in connection with boiler practice, and as the steam turbine reaches its highest economical working conditions with the use of superheated steam, the successful development of the superheater is a most fortunate circumstance.

Steam turbines operating under a vacuum of 28 inches and superheated steam, as above mentioned, have shown an economy equal to that obtainable by the best triple-expansion condensing engines; while in the matter of continuous operation through long periods without shut downs they are eminently suited to the work of generation of power for directly driving pumps for irrigation work.

In this connection the centrifugal type of pump in its recent developments and improvements has kept pace with the demands for improved machinery for purposes described in this paper, and the turbine type, with its more flexible properties in connection with special designs, both as to high head and speed of rotation, is available for use at an opportune time.

There has recently been under serious consideration a plant where it is intended to use the turbine pump directly connected to steam turbines in units which will be the largest pumping units in the world, considering the lift, the capacity being 80,000,000 gallons in twenty-four hours in a single unit, the lifts approximating 100 feet, while the economy expected is very close to that of the most economical waterworks pumping engines of which any authentic tests have

been made. Thus fields may be opened up, in some localities where fuel is sufficiently cheap, for handling water from rivers where the water may not be perfectly clean, and hence entirely debarred from being handled by any form of plunger pump.

PUMPS IN DRIVEN WELLS.

Another irrigation development consists in sinking wells in many localities where the gravel strata contain no large bowlders by driving well casings, 20 inches or more in diameter, and lowering into them high-lift centrifugal pumps and bearings for the vertical shaft. There are many places which have come to the writer's knowledge where this method appears to be practicable, and if a demand for this style of construction were once created, no doubt methods for driving well casings of such large diameters would be developed, and would be the means in many localities of obtaining water from underground sources at moderate expense.

GAS ENGINES.

There are many localities where gas engines of various types, in sizes from 5 to 30 horsepower, form one of the readiest means of obtaining power for small irrigation plants. But the great difficulty which the average man not skilled in mechanics has in handling the gas engine is liable to produce dissatisfaction with it as a reliable machine and to create a general impression of its lack of economy, although in the hands of those who are thoroughly familiar with these small units it is very efficient for the purpose desired.

Large engines, developing thousands of horsepower, have been eminently successful on the European Continent, especially where they could use the waste gases from blast furnaces. In this country they have not been generally used in the past, but at the present time greatly increased interest is being displayed in their use, recent contracts calling for units as high as 5,000 horsepower. In one case, with units of this size, it is necessary to manufacture the gases purposely for the engine.

Close observation of the success of these plants may warrant the adoption of such large units for large irrigation works, where fuel cheap in price and high in gas-making qualities can be obtained.

The gas engine is necessarily an expensive unit to install, and the greatest advantage that can be claimed for it is its fuel economy, but it yet remains to be thoroughly demonstrated that in all-around economy of investment, fuel consumption, etc., it will obtain a higher net economy than other forms of heat engines already perfected and demonstrated. In the case of all these new developments there are special

localities for which they are especially fitted and where they could b used to decided advantage.

WATER POWER.

In many places throughout the West the rivers carrying larg quantities of water have rapids or falls which can be utilized fo power purposes, both electrically and by direct means. Some pre liminary plans have been made for plants of this kind where the bank of the river and the lands adjacent thereto are too high for water t be taken to them by gravity, but where there is plenty of power. A high-lift centrifugal pump may be mounted directly on the shaft o a vertical turbine water wheel, both the wheel and the pump receiving their water from the same source, the water flowing down throug the turbine wheel and up into the base of the pump, there being n external shafts or stuffing boxes. With a water-balanced step bear ing and suitable screens provided, this device will work practically continuously, with very little attention and at small expense for wea and tear.

SUMMARY.

With the rapid demand for means of obtaining water upon lands out of reach of gravity systems, the developments such as have bee treated in this short article will undoubtedly continue, and improve ments both as to cost and economical operation will advance with th demand and with the demonstration of the feasibility of bringing under cultivation lands now utterly useless. It is the belief of th writer that the future holds the most encouraging prospects for suc development, and that those interested in irrigation have only t create the demand and it will be supplied in such measure as wil bring about a satisfactory income from the development of our grea West.

ESTIMATES ON TUNNELING IN IRRIGATION PROJECTS.

By A. L. Fellows.

INTRODUCTION.

I first became intimately concerned with tunnel construction abou eighteen years ago in connection with an irrigation project in south western Colorado. In this project the lands to be reclaimed wer separated from the river which was expected to furnish water fo their irrigation by a divide several hundred feet high. The tunne forming a part of the irrigation system as constructed was 5,400 fee in length, with a cross section of 7 by 9 feet. My connection with thi

project was that of assistant engineer, and there I learned principally what not to do.

As is common with corporate enterprises, the amount of money available was very limited, and it was generally considered that money that could be saved in surveying was economy for the project. As a matter of fact, in this particular case, I have estimated that three-fourths of the actual cost of the project would have been saved by careful and thorough engineering.

The tunnel as constructed was of considerably greater length than necessary and was left unlined, in spite of my protest, on the theory that it was more economical to give it a heavy grade and to leave the tunnel unprotected than to construct lining that might serve as protection.

This tunnel may to-day serve as a typical horrible example. The roof has caved in until there are in places rooms of from 16 to 30 feet in height. The finer material has been washed out to some extent, but the bulk of the material broken down from the roof is left as a menace to the maintenance of the tunnel and an impediment to the flow of the water. It would cost more to-day to put this tunnel in good repair than to construct a new one. I cite these conditions simply as instances of things to be avoided in tunneling, or, in fact, any other kind of engineering work.

My attention was first drawn to the Uncompahgre Valley project, of which the Gunnison tunnel is an integral part, by its similarity to the project which I have just instanced, and in the surveys every effort was made to avoid the mistakes that had been made in the first project.

PRELIMINARY WORK.

The importance of thorough surveying, with reference to any class of engineering, can not be overestimated, and this importance is particularly well illustrated in the survey of the Gunnison tunnel project, which I am now discussing. As a matter of fact, mistakes did creep into the early part of the work, and had the project been constructed as at first contemplated, and as the earlier surveys seemed to indicate was the proper method, it would have been done at an increased cost of several hundred thousand dollars. In my opinion it is safe to say that surveys amounting, at the outside, to not over $8,000 in cost effected a saving of not less than $200,000 in construction. This refers to the construction of the tunnel alone and not in any way to the increased efficiency of the project as a whole, with reference to which it is estimated that the cost has also been lessened by at least another $100,000, and perhaps by twice that sum, through the change.

Location.—The best location for a tunnel having been decided upon in a general way, the details must be worked out with the greatest of

care. The amount of water to be carried, the amount of fall available, the best alignment for the tunnel from both topographic and geologic standpoints, the cross section, coefficients of friction and velocity of flow, are all to be determined as exactly as possible.

The alignment may depend upon a variety of both topographic and geologic conditions. The shortest line may be the best, but it may also be affected by the character of the formation to such an extent that a longer line through better formation may be preferable. It is true that one can not tell what conditions he may meet with in a long tunnel, but with a fair amount of care the probabilities may be ascertained and many uncertainties done away with, at least within reasonable limits.

At first thought it would seem that the natural location for a tunnel was always where the line is the shortest, but the very causes which have made such a location the shortest line may also be of such a character as to prevent easy construction, and possibly provide contingencies which will very materially increase the cost of construction. A saddle between hills often owes its existence to the fact that the erosion which has taken place has been caused by the softness of the rocks at that particular point, or possibly to the fact that there is a fissure at this location which has rendered erosion easy, but tunneling difficult.

Grade.—The grade to be given the tunnel, as is the case in the grading of canals, siphons, etc., will depend upon the conditions. If there is sufficient flow available the tunnel should be given enough grade to carry the amount of water desired at the maximum velocity that will not erode the tunnel lining, this being, of course, for the purpose of decreasing the cross section to as great an extent as possible.

The coefficients of friction depend upon the surface of the tunnel and will range from 0.010 to 0.012 for smooth concrete up to 0.030 to 0.035 for the ordinary rough-rock walls in machine-bored tunnels.

The velocity is dependent upon the grade which can be given. In my plans I have assumed that the lining can withstand a velocity of approximately 12½ feet per second without injury. This high velocity would not be possible if it were expected that the water to be conveyed through the tunnel would carry a great amount of silt but in the project which I am now considering the amount of silt carried is usually inconsiderable.

ESTIMATES OF COST.

General principles.—Assuming that the location of the tunnel has been made with the necessary care, an estimate of the cost of construction may be made. In the course of my investigations with

regard to this subject I have compiled considerable data concerning the cost of construction of tunnels in different localities, much of which, however, I regret to state I am unable to incorporate in this paper, as it was given to me confidentially and is therefore not to be disclosed. It is sufficient to say, in this connection, that the cost per cubic yard of material to be removed may vary from a very small sum, amounting to perhaps not more than $2, up to almost any figure. My suggestions with regard to estimates can be, therefore, only general, the details necessarily being worked out separately for each individual project.

The kind of estimate to be made will depend very largely upon the stage of investigations. For example, in the earlier stages when general knowledge only as to cost of construction is desired, it is quite common to accept figures concerning cost shown by actual construction under as nearly similar conditions as possible in the region in which the project is located. This estimate may be based either upon the cubic yard or linear foot. I have found no very clearly defined idea as to the proper cost per cubic yard in making estimates. Some authorities state that $5 per cubic yard in long tunnels is the time-honored basis for estimate; others state that $6 is more nearly correct, and still other figures are given by other authorities.

Probably the more usual practice is to determine as nearly as possible the cost of similar structures in the vicinity; for example, in the preliminary investigation with reference to the Gunnison tunnel, I found that tunnels of about the same size and in conditions apparently more unfavorable than those surrounding the construction of the Gunnison tunnel had cost, for excavation alone, from $20 to $30 per linear foot. In the two tunnels most nearly like the proposed Gunnison tunnel of which I have knowledge the proprietors, who had done the construction work themselves without the intervention of contractors, informed me that while the excavation had cost them somewhat more than $20 per linear foot, they were certain that under as favorable conditions as they knew to exist with reference to the proposed Gunnison tunnel $20 per linear foot would be ample. Later investigations have demonstrated to my satisfaction that these estimates were not too high, but, in general, those made in this way can be considered as approximate only.

As investigations proceed more nearly to completion and final estimates, before letting contracts, are desired, it becomes necessary to consider the probable cost much more in detail, and then the only proper way of making an estimate, in my opinion, is on the basis of a contractor's bid. Plans must be drawn showing the different varieties of cross section to be used, and the amount of lining neces-

sary for different degrees of hardness of the geologic formati and the probabilities with reference to the finding of water in gr or small amounts must be determined. In the specifications for t Gunnison tunnel an effort was made to do away with all uncerta ties, so far as the water to be encountered was concerned, by inc porating proposals with reference to the amount of water to pumped, thus putting the burden directly upon the Government, a not upon the contractor and thence indirectly to the Government.

Power.—The first details to be worked out with care are th relating to the furnishing of power for construction. A water pow if available, may often be preferred to power derived from the u of coal or oil unless these are extremely low in cost. This subj has been most ably treated by Mr. H. A. Storrs in his valuable pap and need not be gone into at this time. I desire to say, howev that in general I am sure that the Government would save mon by constructing the power plant itself instead of leaving this for t contractor to do. It would lose nothing thereby, as the cost of esta lishing a power plant is well known among contractors, and th would almost invariably allow for the cost of such a plant, wi probably some additional allowance, if they were satisfied th sufficient power would be furnished.

In the matter of the establishment of a water-power plant, a nu ber of instances which have come under my observation have led n to believe that the saving to the contracting party may be sever times the cost of the power plant; in other words, the contracti party is practically losing nothing and may have considerable to ga by itself establishing the power plant. In making the estimate t cost of depreciation upon the plant must, as has been shown by M Storrs, depend upon whether the plant will be entirely used in t construction of this individual project or whether there will be co siderable salvage. In most cases there should be a salvage of fro one-half to one-third of the original cost of a new plant. This h an important bearing upon the estimates, as the cost of the plant a very considerable proportion of the entire cost of construction. Est mates with reference to the cost of a power plant may generally b determined with reasonable accuracy through the aid of the eng neering supply companies, which are always glad to furnish pr liminary estimates.

Labor.—The next item to be considered in detail is that of labo and here, too, conditions will vary widely in different localities. is usual for contractors, in making their estimates, to determine t cost of operation per day as the first step, the amounts paid for lab being different in different localities. In estimates for a 12 by tunnel which I have in my possession I find the following items

computing the cost of excavations at one heading for one day, the number of employees varying with the number of shifts:

Number of employees required in tunnel work.

Rating.	Number employed.	Rating.	Number employed.
Compressor engineers	2 to 3	Trackmen	2 to 3
Compressor firemen	2 to 3	Dump men	2 to 3
General foreman	1	Light men	2 to 3
Shift foremen	2 to 3	Nippers	2 to 3
Timekeepers	1 or 2	Stable men	2 to 3
Machinists	1 or 2	Pump men	2 to 3
Blacksmiths	2 to 3	4-horse team	1 or 2
Drillers	8 to 12	2-horse team	1 or 2
Helpers	8 to 12	Locomotive engineers	4 to 6
Muckers	14 to 21	Brakemen	4 to 6

To these are to be added the cost, varying in the different localities, as before stated, for fuel, water, powder, oil, repairs, carbons, depreciation of plant, insurance on men, pumping water, bond, and incidentals not otherwise accounted for, the last item amounting usually to about 10 per cent of the total cost.

The estimates made by the contractors will probably not vary widely, generally, as to cost per day. The crucial question is as to the amount of work that can be done in one day. For example, in two bids in my possession, the contractor who made the higher estimate of cost per day has assumed that he could do not to exceed 12 feet of work at each heading per day, while the other makes his estimate on the assumption that he can complete, on an average, 18 feet per day in each heading, this decreasing the cost per linear foot in the second case very considerably.

Lining.—The lining will naturally depend upon many different conditions. In some localities, where material for making brick is at hand, it may be thought best to line the tunnel with brick. In others, where construction is intended to be temporary only, the lining may be of timber, with a board surface to facilitate the flow of the water. In the project under consideration it was decided that concrete should be used, and in making the estimates with this end in view the following items were taken into account, the cost of a cubic yard of material in place being computed: Labor, crushing stone or transportation of gravel, or both, as the case may be, sand, forms, placing forms, cleaning bottom of tunnel, drayage, cement sheds, and depreciation on equipment. To the sum of these items should be added

also the cost of cement, although where, as in this case, the cen is furnished by the United States Government, its cost will no included in the contractor's estimate.

Timber.—The amount of lumber used per linear foot may be ea computed and is to be added where timbering is necessary.

SUMMARY.

The summing up of the various items enumerated above, redu according to the best judgment of the engineer, into cost per lin foot for different classes of work, will give his estimate of the act cost of construction. Where it is expected that bids will be ask however, a profit to the contractor must be added. Few contract will estimate on less than 20 per cent profit, and ordinarily 25 cent will be accepted as a reasonable basis.

It is not expected that in a general discussion upon such a sub as this it would be possible to cover all conditions that may ar Only general rules can be laid down and all details must be worl out separately for each individual project. Where the plan outli above is followed, however, it will in general give a close appro mate idea of what should reasonably be expected as bids by c tractors. The engineer must use his best judgment in making th estimates and endeavor to cover all details. Difficulties of an a dental nature that may arise should not be included, excepting in insurance and contingencies as above provided for. The contrac may perhaps make an additional allowance for unforeseen emerg cies, but the fact is generally recognized that although a contrac may possibly make his estimates on the worst possible conditions, contracting party may do the work himself and thus avoid the extre conditions on which the contractor's basis is estimated.

In conclusion I desire to deprecate a too common tendency to ov estimate. It appears to me to be as much of an error to overestim as it is to underestimate cost, and while reasonable allowance for c tingencies should be made, it is not, in my opinion, good engineer to make an additional allowance after the allowance for cont gencies has once been made. I have known of instances where e mates had to pass through several different hands and each individ felt it incumbent upon him, even after expressing himself as sa fied with the details, to add some lump sum for unexpected en gencies "so as to be on the safe side." I appreciate the fact t engineers are often criticised for underestimating, and I deprec this fault as fully as anyone can, but the point which I desire to m is that after the engineer has stated what, in his opinion, is the pro estimate, that amount should be adhered to and neither added to subtracted from, unless some good reason for the change is show

REPORTS AND ACCOUNTS.

By A. L. FELLOWS.

INTRODUCTION.

Of the many difficulties confronting the engineer in the Reclamation Service, none causes more annoyance, probably, than the necessity for frequent reports to his superior officers and for keeping the necessary accounts connected with his work. This condition applies to everyone connected with the Service, from the field assistant of the lowest grade to the chief engineer and the Secretary of the Interior.

It is not my purpose, in this short paper, to go extensively into details, but I desire to submit for consideration a few suggestions along broad lines.

That reports are absolutely necessary evils no one will deny; but to those who, like many of us now in the Reclamation Service, have been engaged for any length of time in private practice, where they were responsible only to themselves and to the individuals or firms employing them, the necessity for reports concerning all kinds of details is particularly trying. Nevertheless, the ever possible investigation, when every item is to be sifted out of the sum total of expenditures and when every act is to be scanned, must be always present before us.

But, more than this, every engineer must wish to have his records and accounts in such shape that he can, for his own satisfaction, lay his hands immediately upon any data or transaction in which he is interested; and, in order to do this, his records must be arranged systematically and be kept strictly up to date.

CHARACTER OF REPORTS.

It is clear, first of all, that there must be a definite system to be followed, and that this system must be so simple as to be readily understood, not only by the engineer himself, but by any other engineer who may be obliged to follow him and to carry on his work. While it must be thorough, so as to cover all essential details, it should not be involved nor should it permit of reduplication. It must not be encumbered with dead branches, making it so overloaded that it may fall of its own weight, but it must, on the other hand, be based upon records showing what the details of cost and methods employed in operation have been, and be sufficiently comprehensive to give a clear conception of the facts.

This system, while it must be complete enough to satisfy the c ditions for which it is evolved, must yet not take the time of engineers unnecessarily, but must present in concise form, for consideration of the higher authority, those facts which are essenti leaving out nonessentials.

The Secretary of the Interior wishes to have before him repo from the Director, and reports from the chief engineer, showi briefly and concisely, work accomplished and progress made in of the different projects and classes of work contemplated and c ried on by the Reclamation Service. He desires to have these repo made in as few words as possible consistent with giving a clear id in the broadest possible way, of the situation.

The chief engineer requires from his subordinates reports somewh more frequent and more detailed in character. He wishes to kn at stated intervals the progress made along all lines of work carri on under his jurisdiction. At the same time, he desires that th reports should be free from unnecessary details, such as the cost individual items, and such events as moving camp and similar trifli matters; but it is highly essential that he have a clear idea of t situation at all times, so that he may talk intelligently concerni projects under his general direction with those who may be intereste

The fact must be remembered that the chief engineer is to a ve great extent the one who stands between the public and those who a doing the field and office work. He is, in fact, almost the court last resort in important matters and sometimes with regard to matte that are relatively unimportant. He, moreover, must take upon hi self the sins of omission and commission of his subordinates wh discussing matters pertaining to the Reclamation Service with me bers of Congress and public men generally, as well as with priva individuals who may be concerned. He must, therefore, be ke well informed not only by means of monthly reports, but by person letters relating to important matters whenever conditions requiri them arise. At the same time, the tendency to annoy him wi descriptions of petty details can but brand the correspondent incompetent to satisfactorily fill his office.

The assistant chief engineer and supervising engineers, who are render decisions in regard to the less important matters not relati to public policy and administration, should be kept informed in mu the same way as the chief engineer concerning work being carried under their supervision.

The consulting engineers should similarly be kept informed co cerning those matters over which they have jurisdiction.

The district engineers in order to make the necessary reports their superior officers must be kept informed concerning the work

each party within their respective territories, and must have within their grasp details of work done and cost of same, with reasons for the prosecution of such work if called upon to give them. The district engineer is concerned both in the results and in the methods adopted to secure them. He must be both initiative and referendum.

The project engineer, in turn, must have all details within reach, including costs, methods adopted, and, in general, everything needed in case of detailed investigations. His office is the depository, temporarily, of accounts which will be looked into, notebooks used upon the project, detailed reports of assistants, plans and estimates connected with his project, whether the same originated in his own office or in other offices. He must receive reports from his chiefs of parties as often as he may need them, to keep him thoroughly informed as to operations in the field and to see that his orders are being carried out and to plan for future contingencies.

Finally, chiefs of parties must have reports from their instrument men and heads of subparties, in order that they may be able to compile intelligible reports concerning all work, whether carried on by individuals or by heads of subparties.

To review the conditions from the other side, the chiefs of parties must be able to report to the project engineer, in such form as he may prescribe, concerning the most minute details of the work carried on under them. He, in turn, after boiling down the details before him until he has those most essential for a clear comprehension of the situation, reports to the district engineer, who, again, reports the sum and substance of all that has been accomplished within his territory to the consulting, supervising, and chief engineers, who report the broader facts for the use of the director and secretary, who may make these facts public through the medium of his report to Congress.

BASIS OF REPORTS.

In devising any system of reports, some well-established principle, upon which all can agree, must be adopted as a starting point. There is in the Reclamation Service one definite and necessary foundation upon which any system must be based, namely, the voucher. This is the final referendum in investigation, and upon this is based the charge sheet which has been adopted in the Service for convenience in bookkeeping. In order to simplify the processes of keeping accounts and of making reports, so far as is possible, it is clear that the same terms should be generally employed as those used in the charge sheet and in the accounting department of the Washington office.

The various divisions made, if it is desired, may be somewhat further subdivided by the district and project engineers, but these sub-

divisions should readily group themselves under the main divisi used on the charge sheet. It would be difficult, and probably imp sible, to find two engineers who, offhand and without concerted acti would use the same terms for facilitating their bookkeeping and describing their work. The charge sheet has, however, been adopt as the result of careful study on the part of several of the engine who have had the most experience in the Service, and will probab with possible modifications as developments may from time to ti require, serve permanently as a basis upon which accounts are to kept and rendered. Reports should, therefore, so far as possib make use of the same terms as those used in the charge sheet.

SYSTEM OF ACCOUNTS.

With reference to reports to be submitted covering both details work done and accounts there is a wide divergence of opinion amo engineers. One class believes that the keeping of accounts and t rendering of reports should be eliminated from field work, and th all of this work should be done, so far as practicable, in the offic the other class believes, to a greater or less degree, varying with t individual, in making each engineer directly responsible for the pu chases made under his direction and for his use, and, in order bring this as closely home to him as possible, he requires his assis ants to make out detailed reports both of the work done and t expenditures incurred.

The former method will undoubtedly result in the best sets accounts, both in appearance and accuracy. They will be made most nearly according to the requirements of the Washington offi and will not, in all probability, contain the irregularities that m be shown in reports made up in the field. This method has t advantage, too, of giving the field man more time to devote to t field work, and does not distract his attention by the petty detai connected with the field accounts. For the reason that the work m be done more expeditiously, as well as better, in the central offi this method is probably cheaper, and, in some respects, more sati factory to the project and district engineers, and perhaps more pa ticularly so to the chief engineer and the army of accountants rangi through the various departments of the Washington offices.

On the other hand, the second method suggested has the advanta of schooling the assistant to the various methods of keeping accoun of expenditures and records of his work in detail, and it is to borne in mind that the field assistant may, at some future time, a in many cases certainly will, be called upon to take charge of t keeping of accounts and to assume the responsibilities connect therewith. The argument in this connection is that, in the en

more is gained by having the field assistants thoroughly trained in the methods of keeping accounts and making reports than in the temporary advantage of having the accounts in better form and appearance. This case is nearly parallel to that of the engineer who has gone through all of the different branches of field work in making surveys. He is a better engineer who has actually, by experience, learned all of the details of chaining, using the ax, rodding, marking stakes, leveling, running transit, plane table, etc., than he who has started with the transit at the beginning and has never gone through any or all of the preliminary steps.

It is true, on the other hand, that this routine work and devotion to details may be carried too far, and, as previously suggested, the system may fall of its own weight. For this reason the processes gone through should be as simple and as little onerous upon the field man as is possible.

The system used by myself was devised for my own needs and without particular reference to the work of other engineers. Later, however, at the request of the chief engineer, I sent samples of the different forms used by me in my survey work (but not as yet with regard to construction work) to all of the different district and supervising engineers. I may say, in passing, that the comments which have come to me have, in general, been commendatory, although a number of valuable suggestions have been made with reference to possible desirable changes.

The system adopted is, briefly, as follows:

The chief of a party or head of any particular class of work, whether he have a dozen men under him, or be doing all of the work with only one assistant, or even by himself alone, is furnished with a time book, consisting of—

First. Instructions to chief of party.

Second. The usual return penalty blank.

Third. Title-page, with blank space for month, State, project, etc.

Fourth. Personnel of party, comprising name, classification, occupation, rate per day, name of person to be notified in case of injury to employee, and permanent address.

Fifth. Monthly time record in the usual time-book form.

Sixth. Several pages for daily record, which are nothing more nor less than a form of journal intended simply to help the assistant to keep track of important incidents and to furnish him with a regular place for keeping memoranda of purchases, etc., space being provided also for an estimate of the salary expenses for the day upon the several classes of work under his direction. Some would make this even more extensive.

Seventh. The last two pages of the book are devoted to a monthly summary, using the subjects for secondary and tertiary division used in

the charge sheet, subdivided to some extent, but grouped under the classifications shown therein, this monthly summary being for the purpose of familiarizing the assistant with the terms used and with the nature of the work which has to be done in the accounting division. Some of my correspondents would prefer to leave this out entirely.

Experience has shown that it takes but a few minutes' time on the part of the chief of the party each evening, and two or three hours at the end of the month, after he has become familiar with what is expected of him, to keep his book in satisfactory condition. He may, if he desires, keep a duplicate for his own use and records, but the original is to be turned in as his report promptly at the end of the month to his superior officer. It is to be accompanied by such written statements as he may wish to give in describing the work done under his direction, which statements should refer to the orders of his superior officer, and give such details as the assistant may conceive to be of importance in connection with his work. It should, in some cases, be accompanied by sketches, which in the work under my supervision are expected to be made upon progress maps, compiled in the office for use in the field.

The chief of each party is expected, moreover, at the end of each week, to keep both the project engineer and the district engineer informed as to the progress of his work, by means of Form 9–512, which consists simply of a journal of the week's work, with space for comments concerning work and for a forecast of the work to be done during the ensuing week. I find these forms of considerable value in keeping me in touch with the work going on. It is expected, of course, that the chief of party will also write detailed letters in case there is anything requiring particular attention or in case there is not enough space on the form. His reports, however, are all to be on sheets of the same size as the form, which is of the ordinary letter size.

At the end of each month each chief of party or individual having direct charge of important work is expected to send in a summary for the month on Form 9–518. It is intended that but little time should be required in filling out this form, which, in the main, is arranged on the plan of the charge sheet. Instructions are given on the back of the same for its use, and thus far those who have made use of it have expressed satisfaction with the results obtained.

Form 9–514 is intended as a means of grouping together the reports from the chiefs of parties, so that they may be submitted as a whole to the project engineer. It is not essential that copies of Form 9–518 be sent to the district engineer with the summary, although it is desirable at points where there are auditing departments capable of going over the various reports and checking the results.

In general, it may be said that Forms 9–515 and 9–512 would be

almost universally accepted among the engineers, while 9–514 and 9–518 are forms which some engineers would not have made up in the field, but the information upon which would be gleaned from the office records. Much could be said upon both sides of this question, but the main point is that records of this character should be available from some source, whether made up in the office or in the field, and these forms have thus far seemed easily comprehended and to require but little labor. To make their use possible, that must be done which I assume is done in every well-organized office, namely, purchases must be made upon requisition and the purchaser must be furnished with an itemized statement showing each purchase made, with cost of same. In all of my work I have these requisitions made in duplicate—that is, with an original and carbon copy, the original being left with the merchant from whom the goods were purchased and the carbon copy being retained in the office.

REPORTS ON CONSTRUCTION WORK.

The system devised for reports upon construction work is somewhat more extended, although simpler in its nature. It proceeds along two lines—first, on the supposition that the office must be kept informed concerning the work actually done by the contractor, and, second, that the office must have as definite information as possible concerning the actual cost of construction to the contractor.

In the first group the field quantity book is naturally the basis. From the quantity book quantity sheets are made, showing the amount of material removed and the amount of work done. These are to be made up by the division engineers and forwarded to the project engineer, in whose office they will be kept on file. Next is a form for the purpose of showing the total amounts of work done by the contractors, this being compiled from the quantity sheets. Last is a form for the purpose of making a statement of the amount to be paid the contractor, a copy of which is forwarded to the district engineer, and, after being checked and approved by him, to the chief engineer. With this statement is a graphic representation of work actually accomplished and payments to the contractor.

The second group is based upon the time book and is for the purpose of determining, as far as possible, the cost to the contractor and his consequent profit or loss. The timekeeper keeps a time book of the kind ordinarily used in similar work, and at the end of each week or month makes his report upon a suitable form, showing the amount of labor and materials paid for by the contractor. These reports are forwarded to the project engineer, in whose office a more detailed report is compiled, showing the cost to the contractor. These reports are filed away as matters of record and are not necessarily sent to

cent of its mass in water, not more than an average of 5 to 8 per cent could be withdrawn by the application of pumps or other gravity force. Again, in other localities, where the fill is of coarser particles and more uniform in size, although the amount of water contained would not be more than 25 per cent it would be possible to extract four-fifths of this, either through pumping or by tapping the deposit at a lower level.

SOURCES OF SUPPLY FOR UNDERGROUND RESERVOIRS.

The sources of supply which have filled these reservoirs of drift material are three in number—(1) the precipitation on the mountain watershed bounding the basin where the water is to be found; (2) the precipitation upon the valley land itself, part of which enters the ground, and (3) the return waters from irrigation on areas lying above the basin.

By an inspection of the United States Geological Survey maps of the Redlands and San Bernardino quadrangles it will be seen that San Bernardino Valley, for example, has a number of large gravel washes running from the various rivers, creeks, and mountain canyons into and across the valley. These gravel washes comprise a considerable area of the land adjacent to the foothills, and where they enter upon the valley lands are designated by engineers as "débris cones." This title is derived from the fact that they are fan-shaped deposits of coarse drift, which bear something of a resemblance to the side of a cone. When the flood waters from the mountains are deposited at the mouth of a canyon, they pass over these débris cones, permitting a certain amount of the flowing water to sink below the surface. The water thus sinking is not again drawn to the surface and evaporated, but percolates gradually until it enters the valley or basin below, where it furnishes by far the most important source of supply of the underground valleys of southern California.

Next in importance, viewed from the state of nature, but not in volume, under the present artificial conditions produced by irrigation, is the rainfall upon these valley lands. The water falling upon the surface penetrates to various depths, depending upon the nature of the ground and the amount of annual precipitation. Where the ground is porous, and in years of good rainfall, a considerable quantity of water is added to these underground reservoirs in this manner; on the other hand, where the ground consists of fine clay, very little, if any, is added to the supply. Since the extension of irrigation and the diversion of all the normal flow of streams in the valleys of southern California, another source of supply has been added to these underground reservoirs. It is well known that when water is applied to the surface for irrigation purposes a certain per-

centage of the water is evaporated, another part is consumed by plant life, and the remainder absorbed by the ground. As in the case of rainfall, if the water absorbed by the ground reaches a depth below the surface from which capillary attraction can no longer draw it up and cause it to be evaporated, it descends and becomes a part of the supply in the underground valley reservoir.

EXTENT OF UNDERGROUND WATER SUPPLY.

Much investigation has been carried on to determine the extent of the underground water supplies in southern California. All investigators have reached about the same conclusion, that the supply produced by nature annually for the replenishment of these reservoirs is limited. While it is considerable in years of abundant rainfall, it becomes almost nothing in years of minimum precipitation, and a mean must be drawn so that the reserve supply is not withdrawn to such an extent as to imperil this resource. Up to the present time this has been much neglected, and the haphazard and reckless way in which promoters have attacked the underground water supply of southern California has demonstrated the necessity of future retrenchment. A great number of cases may be cited where one company has obtained a supply of water by underground development, soon to find that some one else would follow them and either take away a portion or all of their supply. Cases of this kind became so numerous that the matter had to be brought to the attention of the courts, and much expensive litigation has been the result.

LEGAL PROTECTION OF UNDERGROUND WATER.

At first the courts were inclined to treat the subject in the same manner as the law regarded it in regions of abundant rainfall, permitting to each man the right to take as much of the water percolating in his own land as he could use, regardless of the purpose to which it might be put or the locality where it would be applied to the desired use. The defects of this rule, however, became so apparent that the supreme court of California saw the necessity of so interpreting the common law as to adapt it to the conditions prevailing in that State.

The first important case in the State of California on this subject was the now famous case of Katz *v.* Walkinshaw, reported in California Reports, vol. 141. The decision in this case established the rule that underground percolating waters, even when existing in the soil of a proprietor, could only be devoted to reasonable use on the freehold itself. Under this rule it will be possible to protect all legitimate uses of the percolating waters in the land and to prevent

to come from this source. It is possible, however, for the users o water being pumped from these valleys to increase the suppl another way.

Replenishment by floods.—As has already been pointed out, principal source of supply for this underground water is the f water which is discharged from the mountain watersheds adjac When these flood waters enter the valley they issue forth in a nar and contracted channel at some point across the débris cone imm ately below the mouth of the mountain canyon. The opportunity percolation from the stream when flowing is limited to the are surface over which it passes. The material being porous, a con erable amount of water percolates down into the strata, even in narrow channel occupied by the water. But, on the other hand is undisputed that when heavy floods occur the greater part of flood run-off passes over the surface, down the various stream ch nels, and eventually into the Pacific Ocean. If some means can adopted whereby a greater percentage of the flood water may e the débris cones along the upper margin of the valleys, it follows t the supply to the underground reservoirs can be increased co spondingly, and this is an ideal which is not impossible of realizati The areas of these gravel washes are very extensive, and if the fl waters, instead of running in a narrow channel, were spread over the débris cones the result would be to feed the undergro reservoirs much more rapidly than is possible in a state of nat In order to accomplish this it will be necessary for those interes in the water supply of these underground reservoirs to constr regulating works at the mouth of every mountain canyon of suffici importance, by means of which the flood waters can be control and uniformly distributed over the large areas of gravel wash im diately below each canyon. Such works would have to consist o dam or dams, with outlets at a sufficient number of points to charge the water on the gravel wherever desired.

In addition to the dams, shafts or wells might also be excava at points lower down, into which streams of water might be run, t affording the infiltration of water into the gravel débris cone un pressure. These dams should be so constructed that the water mi be shifted from place to place as required.

This feature is extremely important, because when flood wa heavily charged with silt flows over the débris cone in one place fo considerable period the fine silt carried by the water fills up the po and prevents rapid percolation into the detritus.

In connection with such works for controlling and distributing flood waters over the débris cones it is, of course, important that t be so constructed as not to direct the floods upon the agricultu areas adjacent, thereby causing damage to improved property.

While the accomplishment of this method of recharging the underground areas of southern California seems a very simple one, it involves problems in hydraulics which are possibly more important than have heretofore been encountered by the engineering profession. Not only is the question of designing these works so as to make them commercially economical a very important one, but the question of so designing them as not to damage adjacent improved property is one of still greater importance. These floods are sometimes so enormous that to divert them from their accustomed channel might be a serious menace to many localities, for which reason the works must not only be substantially built, but must be so designed as to allow complete control of the water discharged during the heaviest floods.

PUMPING FROM UNDERGROUND RESERVOIRS.

When some of the ideas above outlined are put into practice, as can without doubt be accomplished successfully, the fears now existing as to the giving out of the underground water supply in southern California and the abandonment of localities now under cultivation will be wholly dissipated. The subject of pumping water in southern California is, therefore, not one of mere passing importance, but one which will engage the attention of the people in this section for all time. It is an industry which will forever flourish and be extremely important, becoming more so as the question is solved whereby the right to the use of this water is definitely decided and the quantity which can be obtained from this source is definitely determined. When this period is reached the troubles incident to the interference of one locality with another, or one company with another, will be eliminated, and the whole industry will be founded upon a fixed and conservative basis.

The question of methods and extent of pumping operations is therefore a very important one and merits thorough description.

EXTENT OF PUMPING OPERATIONS.

In the part of southern California lying south of Tehachapi Pass, and embracing the great valley of southern California having its outlet to the ocean below Los Angeles, as well as a large number of smaller valleys, the number of horsepower devoted to pumping water for irrigation and other purposes approximates 10,000. At times the number of horsepower employed is even greater, but the average is not far from the figure stated.

As to the amount of water being pumped by this power it is difficult to state exact figures, owing to the fact that so many of the pumping plants are in operation only for short periods when the owners require the water. Plants operated by large companies and

municipalities are in operation most of the time, but individual plants are used as the exigencies of the owner may demand. The average quantity of water pumped has been variously estimated by different authorities to be the equivalent of anywhere from 350 to 550 second-feet, continuous flow. The making of such an estimate, however, is attended with considerable difficulty, owing to the fact that pumping operations are governed to such a large extent by climatic conditions. In some seasons, which we denominate "dry years," the pumping of water is carried on during almost every month of the year, while in other years, of more abundant rainfall, it is confined principally to about six or seven months. The estimate of the author is that an average quantity of about 450 second-feet of water has been pumped during the last few years from the various underground-water sources of southern California. This, as will be shown by the reports of stream gagings in southern California, is a much greater volume than the combined flow of all the running streams during the summer season of an average year.

METHODS EMPLOYED IN PUMPING WATER.

The means by which this large volume of water is pumped vary greatly. The type of pump employed is probably more uniform than any other feature, as the centrifugal pump is principally used. Some other types of pumps are in operation in places where the water is to be lifted a considerable height, but these are the exception rather than the rule.

The kind of power employed in driving these pumps varies considerably, being, in the order of their importance, as follows: Electric motors, gasoline engines, and steam plants. The application is either by direct connection or by belting, the latter being at present the most popular and most widely used. In the case of electric motors the author is convinced that the efficiency can be increased by a direct connection of the motor to the pump, particularly in the case of centrifugal pumps.

Efficiency of pumps.—A method of pumping which has been employed to some extent is to drive an air compressor by means of either of the three kinds of power above stated, forcing down into the well the compressed air, which, upon escaping, throws the water out of the casing. This method is known as the direct air-lift or Pohle system. The economy of power with the direct lift is very low, as the efficiency of an air compressor is usually as low as somewhere from 50 to 60 per cent, and the air discharged in the water only exerts about one-half of its useful energy in lifting water, the balance escaping in the form of bubbles to the surface. The result is that the direct air-lift method of pumping shows an efficiency of

only from 20 to 30 per cent of the actual power applied. This makes the method undesirable where a first-class pump can be operated to advantage; but it has its use in the case of a large number of wells scattered over a radius of half a mile or thereabouts, which may be operated from one central station without individual plants at each well. In a case of this kind the compressor can be installed in the central station and the air piped to each of the wells from this point. The loss due to inefficiency in the use of power is, therefore, in such cases overcome to a great extent by avoiding a multiplicity of small plants and attendants to look after them.

As to the efficiency obtained from the power applied to other pumps, it has been found to vary from 40 to 75 per cent. The worst cases of installation which have come under the observation of the writer were where centrifugal pumps have been used and show an efficiency of about 40 per cent, the best being about 75 per cent. This range also applies to other pumps, such as the Downey double-acting deep-well pump, as well as to triplex and quadruplex pumps of various makes. With proper installation there is no reason why the efficiency should ever be below 65 per cent in case of any of these types of pumps, and with the very best design it should in three-fourths of the cases be up to 75 per cent. The faults which account for the inefficiencies in most cases are in selecting the size of pump required and the method of arranging the installation of the apparatus. These plants are frequently installed either by agents, who are not themselves familiar with points relating to the operation of such machinery, or by the owners of wells themselves, who go ahead without any technical assistance. However, the people are gradually learning that economy in operation is a very important essential, and that the investment of a few less dollars in the initial cost is not so important as the securing of a continuously high efficiency.

Electric power for pumping.—While streams in southern California are not large in volume during the season of normal flow, they possess another feature, viz, that of having steeply inclined beds. The grades of the streams flowing from the mountain watersheds vary from 100 feet to 400 feet per mile. This fact makes it possible to obtain high falls in the mountains, from which electric power can be developed. The result is that there is not at present a stream of any importance on which there has not been constructed one or more hydro-electric power plants. In the development of these powers the Edison Electric Company, of Los Angeles, has been the leader up to the present time, having developed and put in operation 6 plants of this kind and being engaged at present in the construction of several more. The output of these plants is largely

used for pumping water for irrigation and other purposes, and description of the methods of constructing them is therefore of gre value in this connection.

Of the plants which the Edison Electric Company has in operati at the present time, the first was installed on Mill Creek, ne Redlands, in the year 1893. This plant has a net fall of 510 feet, an the water is carried through a 30-inch steel force main 10,250 feet i length. This is the only plant that may be termed a "valley" plan the diversion of the water being at the mouth of Mill Creek Canyo and the pipe line and power house being entirely in the valley. Th fall of the valley at this point, however, being more than 250 feet pe mile, made the construction of the plant easily possible. The appa ratus installed in the station of Mill Creek No. 1 is three 250-kilowat generators, driven by Pelton water wheels. These generators a their estimated full load develop 1,000 horsepower, but have fre quently been loaded 30 or 40 per cent over their rated capacity. A the time of its installation this plant was considered large and impor tant, being the first commercial three-phase plant in the world. Late developments of the company, however, have made this plant appea small and insignificant.

Two other plants have been installed higher up on the sam stream and are known as "Mill Creek No. 2 and No. 3." The forme of these was constructed in the year 1898, the fall available at th water wheels being 627 feet. This plant derives its water from tributary of Mill Creek known as "Mountain Home Stream" an from certain other water rising in the bed of Mill Creek itself belov the next diversion, known as "Mill Creek No. 3."

The water is carried in a cement-concrete pipe line along the side o the mountain and through numerous tunnels to a fore bay, from whicl point the force main of steel pipe, 18 inches inside diameter and 1,40 feet in length, delivers the water to the power station. The machiner installed in this plant consists of two 250-kilowatt generators, als driven by means of Pelton water wheels.

The plant on Mill Creek known as Mill Creek No. 3 is remark able on account of its high pressure at the wheels. The net fall fron the fore bay to the power-house floor is 1,960 feet, being through a stee force main about 8,000 feet in length and varying from 28 inches to 2 inches internal diameter. The water is diverted from Mill Creek at point near Akers Narrows, which is situated nearly 5,000 feet abov sea level, and carried through a cement-concrete pipe 31½ inches i diameter, laid on a grade of two-tenths of a foot per 100 feet. Thi pipe is buried in trenches or laid through tunnels. These tunnels of which there are 19 on the line, vary in length from 300 feet to 1,10 feet.

The method of making the cement-concrete pipe referred to is b

using a form consisting of two parts, the inside being known as the core and the outside as the jacket. The core when expanded has an outside diameter equal to that required for the inside of the pipe section, and the jacket when closed has an inside diameter equal to that required for the outside diameter of the pipe section. The space between the two when placed in position constitutes the thickness of shell for the concrete pipe, which in case of 31-inch pipe is 2¾ inches. The forms when set up and in position for making pipe are placed upon a cast-iron ring, which gives the lower end of the pipe section an ogee form. The core is expanded by means of a locking device, by loosening which it can be contracted to a lesser diameter. The reverse is true of the jacket, which is contracted by means of a similar device, the loosening of which allows the jacket to be expanded.

The making of the pipe is accomplished by mixing sand and finely crushed rock in equal proportions, and again mixing this, in the proportion of 1 to 3, by measurement, with hydraulic Portland cement. This is shoveled into place between the core and jacket through a hopper and tamped thoroughly until the entire space is filled. The hopper is then removed and a heavy shaping ring is placed on top of the jacket, which shapes the upper end of the pipe section to correspond in reverse to the lower one. The core is then pulled while the shaping ring is still in place, after which this is removed, but the outside jacket is not taken off for about thirty or forty minutes, or until the concrete has taken on its initial set. The pipe section is then left on the cast-iron ring for two or three days until it can be lifted off with safety.

To render them impervious these sections are later coated with a wash of neat cement dissolved in water to cover the entire interior surface.

The method of laying these pipes is to place them together, so that the recess in the end of one section fits the projection of the other. A collar of cement mortar, mixed with 1 part cement to 2 parts sand, is then applied, by means of rubber gloves, around the entire outside and underneath the pipe. This collar varies in size, depending upon the diameter of the pipe; the general rule being that it should be twice as wide as the thickness of the pipe shell and not less than one-sixth as deep at the point of juncture of the two pipes as the thickness of the pipe shell. The crack formed on the inside of the pipe where the two sections are joined is carefully plastered with a trowel to make a smooth and continuous surface. Great importance attaches to having the ends of the pipe section well cleaned and thoroughly wet before the mortar for making the outside collar or plastering the interior is applied, and also to covering carefully the collar or band after it is completed.

After the pipe joint is well set, the trench is then back filled w earth, covering the pipe to a depth of about 18 inches. It is desirable to cover the pipe any deeper than this with fresh ea owing to the danger of the external pressure cracking or disturb the concrete, but later on, after the earth has thoroughly set arou the entire outside circumference of a pipe section from natu rainfall on the surface, it may be covered to any depth. This meth of constructing a hydraulic conduit for power plants has been fou very economical and efficient, as the conduit is buried under ground where no slides, washouts, or rolling bowlders can injure it

The Edison Electric Company has also constructed its hydrau conduit for the power plant owned by it on Lytle Creek, in S Bernardino County, in the same manner, using in this case a 36-in diameter pipe having a shell 3 inches thick.

These three plants, the two on Mill Creek above referred to a the one on Lytle Creek, have been in operation a long time and accidents of any kind have occurred to the pipe. They are in condition which warrants the belief that they will last indefinitely.

The company has, in addition to the three plants on Mill Creek a the one on Lytle Creek, two other plants, located on the Santa A River, also near Redlands. These plants are known as Santa A River No. 1, which was constructed in 1898, and Santa Ana Riv No. 2, constructed during 1904. The volume of water for the plants is so much larger than for the others already discussed th it was impossible to adopt the type of construction already describe It was therefore decided to drive tunnels through the sides of t mountain. These tunnels are lined with concrete and when finish are 5 feet wide on the bottom and 6 feet high, the sides being ru up straight for 4½ feet, after which an arch is sprung over the middl The capacity of these tunnels is 100 second-feet of water; the fall the upper power plant being 728 feet, and at the lower one, or No. 310 feet.

The most remarkable installation yet completed by the company the No. 3 plant on Mill Creek, owing to its extremely high head, t pressure at the nozzle of the Pelton wheel being 840 pounds to t square inch. The pipe used at the lower end of this force main is the lap-welded pattern, with solid steel flanges welded to each pi section. As the thickest pipe—of 24-inch diameter—which could made by the National Tube Company was three-fourths of an inch, became necessary to wrap the lower end of this pipe for the for main to give it the requisite strength. This was done with crucibl steel wire three-sixteenths of an inch in diameter, applied under te sion while the pipe was being turned in a lathe, and securely clamp at both ends of the pipe section. The pipe was then dipped in a ba of asphaltum to cover the surface of the wrapping thoroughly.

The total capacity of the six power plants of the Edison Electric Company above referred to is 15,000 horsepower, nearly one-third of which is being used for the pumping of water for irrigation and domestic purposes. The remainder of the power is distributed for lighting and street-railway operation in the various cities of southern California.

Another large electric-power plant, to be located on Kern River, is now in course of construction by the company, which will have a total output of 28,000 horsepower. This plant will consist of a line of tunnels (8 miles in length), divided into 19 sections and worked from 38 headings. The size of these tunnels in the rough is 9 feet by 9 feet, the sides being 7 feet vertical with an arch overhead. The entire bottom and sides up to 7 feet will be lined with concrete, reducing the section to 8 feet by 7 feet in depth. Overhead lining, in the form of a concrete arch, will be used only where the rock is not sufficiently solid to be self-supporting. Over half of these tunnels, or about 4½ miles, were completed January 1, 1905.

The force main for this power plant will be an inclined underground tunnel, which will be lined with a steel tube 7½ feet internal diameter, the space between this steel lining and the sides of the tunnel being filled with concrete well rammed into place. The grade of the tunnels leading to the head of the force main is at the rate of 7.92 feet per mile, giving the lined section a capacity of about 460 cubic feet per second. The water thus carried will have a net fall of 872 feet from the head of the force main to the water wheels in the station.

The development of this large plant was made necessary by the enormous expansion of business in the part of southern California over which the lines of the company extend, a great deal of this business being occasioned by the amount of power used for pumping water.

The lining of the tunnels with concrete, as above stated, has been found to be the most economical method of constructing them, because the section of a tunnel of given carrying capacity is reduced by smoothness of interior. Taking Kutter's formula as the method of calculating the capacity, the tunnels driven in the rough by means of machine drills will give a coefficient of roughness from 0.028 to 0.035, while the lined and plastered section has a coefficient not exceeding 0.012. It is therefore cheaper to provide the concrete lining and plaster than to excavate the much larger section required for carrying the same quantity of water through a tunnel in the rough.

Other powers used for pumping.—Largely because the electric development has not been able to supply the demands for power a great many individuals and companies have had to resort to the

use of gasoline and steam plants to lift their water. The gasoli engines used are operated with distillate, which is a crude oil havin the heavier ingredients removed. The cost of this fuel is not exce sive, but the amount of attendance required for small plants mak the operation quite expensive. In the case of an electric motor t machinery will run without an attendant after being started, b with a distillate or gasoline engine some one has to be in attendan to guard the operation of the plant. This is also true where stea plants are used, as in that case a fireman and engineer must be i constant attendance, both night and day.

It is likely that as the development of electric power progress the supply will be sufficient to displace most of these less economic plants with electric motors. Although the electric companies su plying power for motors do not usually make a rate which is low than the cost of fuel for other plants, the saving in other directio is so great that the change will be adopted by users of power.

Not only is the saving of attendance above cited an important ite but the greater durability of electric machinery is really still mo important. An electric motor is a piece of machinery which, if n abused, will endure for an indefinite time, while all types of engin are limited in their life to only a few years. Particularly is th true when they are operated (as is usually the case) in pumping plan by men who are not skilled in handling power machinery.

PUMPING IN CENTRAL CALIFORNIA.

The counties of central California from Fresno County to th Tehachapi Pass, including the counties of Fresno, Tulare, King and Kern, are usually classed with southern California when th State is considered in only two geological divisions. These countie include what is the best part of the San Joaquin Valley, which need greater irrigation facilities alone to make it a real empire. All th waters of the rivers flowing into this portion of the San Joaquin Val ley are now being used for irrigation, but the supply is sufficient t irrigate only a small part of the available land. The whole valle however, is underlaid with an abundant supply of water, which i most localities is suitable for irrigation purposes if pumped to th surface. A beginning has already been made in this direction, an the Mount Whitney Power Company, in Tulare County, is now su plying large quantities of power for pumping water to irrigate lan in that locality. This power plant is constructed on East Fork o Kaweah River, and more than half its output is applied to pumpin water at the present time.

In Kern County a plant owned by the Bakersfield Power, Trans and Light Company is constructed, from which a great part of th

output is used for pumping wells in the vicinity of Bakersfield. The water from these wells is used largely for growing alfalfa and for irrigating deciduous fruits, which grow luxuriantly in that neighborhood.

With a greater available supply of power for pumping purposes the extension of irrigation in Kern County, by means of pumping, will be greatly increased. In Fresno County there are large areas of land on what is known as the King River delta, which can be reclaimed by means of wells and electric power developed from the Sierras.

The King River Power Company, a corporation under the Edison Electric Company, of Los Angeles, is the owner of the power rights on King River near Fresno, and the development of these powers will create endless possibilities for the irrigation of land from subterranean water in this part of San Joaquin Valley. The amount of water power which can be developed at normal flow of the streams from the King River Canyon, at Fresno, south to Tehachapi Pass, will approximately equal 200,000 horsepower, and unquestionably there will be a market for all of this power, as a great part of it is needed in southern California, south of Tehachapi, and another large part will be required for pumping water in San Joaquin Valley in the counties above referred to. It is hard to realize what will be the condition of the population in this part of the San Joaquin Valley when these developments are completed to their fullest extent.

No danger need be apprehended from the decline of the subterranean water supply even if used in large quantities in this manner, as the water taken out will be applied to the surface of the valley itself, and a very large percentage will again enter the ground, the only loss being from evaporation and the consumption of the crops grown on the land.

The cases in which the underground water supply is seriously impaired by its being pumped for use are those where the water is carried out of one basin or valley for use in other localities, so that the return waters from irrigation do not reenter the same strata from which the supply was derived.

SUGGESTIONS AND CAUTIONS.

In concluding these observations it is important to state a few facts relating to the proper method used in deciding on projects where lands are to be reclaimed by the use of underground water.

First, it must be definitely ascertained that the supply is ample for the purpose intended and will not give out as soon as the locality built up from its use has become large and prosperous. This is

particularly important where the water taken from one valley is be carried to another distant from it. In this case it must be ca fully ascertained that the supply entering the basin from which t water is taken is sufficient to replenish the voids created by the wat being pumped out. It is also important to determine that the pr posed pumping operations will not interfere with other vested wat rights in the streams or springs in the vicinity, and that they w not draw away the water belonging to other landed proprietors in t vicinity. Where the water is taken out and used on the land und which it is discovered, these considerations are not so important, but a small part of the supply can be consumed at the most. In su cases the percentage consumed will of course depend upon the natu of the soil, the kind of crops grown, and other natural conditions the vicinity.

Another important consideration is the character of the water, b cause injurious salts, if contained therein, may result in the infertili of the land to which such water is applied. This subject must, course, be investigated by careful analyses of the water and of the so to be irrigated.

The proper construction of the plants for lifting the water an distributing it to the points needed is equally important and requir careful attention from men skilled in this class of engineering.

COLLECTION OF STREAM-GAGING DATA.

By N. C. Grover.

A general study of the records of stream gaging brings to th attention the fact that the degree of accuracy varies much for differ ent river stations and sections of the country. Measurements mad for several years at carefully maintained stations have been con sistent, and the measured discharges when plotted have defined closel for each station the discharge curve. Such records indicate tha the laws of river hydraulics are definite and that inconsistencies i measured discharges are due to causes which can be determined an eliminated.

In contrast with these stations are many at which the physical con ditions are just as good, but for which the discharge measurements even in a single year, are glaringly inconsistent. For many such sta tions, with practically stable conditions of bed and banks, as man as 30 to 60 meter measurements of discharge for each station hav been made without defining the curves of discharge.

It therefore becomes a matter of importance to determine the rea sons why the records for some stations are good and for other station

poor. Causes for such differences have generally been found to be either (1) inaccuracy in the determination of areas, (2) changes in the datum of the gage, (3) inaccuracy in the determination of velocity, or (4) poor conditions at the gaging station.

Probably the most frequent source of error is in the determination of the area of cross section of the streams. At high stages of the river, particularly, accurate soundings are difficult and expensive to obtain, and even if sufficient lead is used to insure its position on the bed vertically under the point of observation, the bowing of the sounding line, due to the force of the moving water, will frequently cause errors of several tenths of a foot in the soundings. Errors as great as 30 per cent have not uncommonly been introduced in high-water measurements through errors in the determination of area.

If the bed and banks are permanent, the profile of the cross section should be accurately determined during a low stage of the river, and in computing the results of all meter measurements area should either be determined from this standard cross section or be checked by comparison with it.

Whenever possible the station should be so located that the conditions of flow will be permanent—that is, the conditions of bank and bed should be practically permanent, not only at the station, but within such limits above and below that there will be no appreciable change in the relation between gage height and discharge. In some sections of the country this may be practically impossible, but in others such conditions are not uncommon. Results of gagings at such stations should always be consistent.

If the beds change only during freshets a succession of cross sections, determined at the low-water stages and each applicable for a limited time, can probably be used to advantage. If the bed is constantly changing, soundings must of course be made at each gaging, but exceptional care must be used in order to insure even passably good results. Particular attention is here called to the fact that in order that the areas may be readily checked by comparison with others the total area of both still and moving water must be included.

Next to errors in determination of area are those due to changes in the datum of the gage. A score of cases can be easily cited where several years' records have been rendered almost worthless by carelessness in maintaining a constant datum. Frequent checking of the gage with a permanent bench and an exact and detailed record of just what and when changes have been made is absolutely essential to good results.

Inaccuracies in the determination of velocity may be divided into two classes, (1) those that are due simply to erroneous observations and which are as likely to be positive as negative and are consequently

compensating, and (2) those due to defects in the meter or its rating, which may persist through many measurements. These latter are by far the more important and should receive consideration. They are due to either original inaccurate rating of the meter or to injury of the meter after rating, usually the latter. In order that these errors may be reduced to a minimum, care should be exercised that the meter receives no blows, is properly adjusted, and that the pivot point is protected and oiled. Results should occasionally be compared with those obtained by another meter. If at any time the mean velocities when platted throw suspicion on the meter, it should either be rerated, or compared directly with another meter. If the instrument must be used after injury or when in poor condition, it should be rated before repair and the rating table so obtained applied to previous measurements.

A large Price meter should not be used when the velocity of the current is less than 1 foot per second, nor a small Price when the velocity of the current is less than 0.05 foot per second.

It is worth noting also that at many stations where conditions are permanent, as outlined above, the growth of grass in the stream at the gaging station may decrease the flow as much as 25 per cent from the normal, and this one fact would doubtless explain why many current-meter measurements do not plat well on the curve. Such conditions should be noted in all cases.

At gaging stations where conditions are permanent, therefore, the rating curve may be constructed from measurements made in several years, and should be good for all time. As a result of this investigation the writer has come to believe that if more time had been expended in maintaining the station, in making, computing, and checking each measurement, better estimates could have been made at a smaller ultimate cost. In other words, the careless and hastily made meter measurement is believed to be more expensive in the end. It is therefore suggested that after a meter measurement of flow has been made and computed it should be tested by the man who made the measurement before the results are transmitted, by platting the computed discharge, area, and mean velocity, and by comparing these platted results with others obtained at the same station. If discrepancies are found, the causes should if possible be at once located. An early study of each measurement will insure that mistakes in area and datum of gage shall not be carried forward indefinitely and that reasons for erratic data shall be determined if possible. If a few months or years elapse before any study of these errors is made the results must generally remain uncorrected and frequently will be much in error. It is good business to spend a few dollars in carefully checking and reporting records which cost many more dollars to collect.

RIO GRANDE PROJECT.

By B. M. Hall.

The writer prepared and read at the El Paso Irrigation Congress a paper on "Plans for irrigation of the Rio Grande Valley," which has been published in full in the Third Annual Report of the Reclamation Service. As a supplement to that paper it has been thought desirable to epitomize the unique conditions and engineering facts brought out by it and some of the results that would naturally follow from the completion of the Engle dam and the irrigation of 180,000 acres in New Mexico, Texas, and Mexico.

WATER SUPPLY.

Engle, N. Mex., is about 100 miles up the river above El Paso, Tex., and the annual discharge of the river is much larger at the upper station than at the lower station, as shown by the following table, which gives the discharge at each point in acre-feet:

Discharge of Rio Grande.

Year.	Discharge at San Marcial, above Engle.	Discharge at "The Pass," above El Paso.
	Acre feet.	*Acre feet.*
1897	2,225,257	1,374,745
1898	964,677	[illegible]
1899	239,835	[illegible]
1900	484,324	[illegible]
1901	[illegible]	[illegible]
1902	[illegible]	[illegible]
1903	1,272,000	[illegible]
1904	[illegible]	[illegible]
Total for eight years	[illegible]	[illegible]
Average per year	[illegible]	[illegible]

These figures show that in flowing from San Marcial to El Paso the river suffers an average annual loss of [illegible] acre-feet, or more than 37 per cent of its water, by irrigation, evaporation, and percolation.

The records also show for San Marcial a minimum annual discharge of [illegible] acre-feet and a maximum annual discharge of 2,225,257 acre-feet. [illegible] for El Paso [illegible] greater discrepancy between [illegible] then, to get a [illegible] supply of [illegible] acre-feet for irriga

tion, the reservoir at Engle must be very large and must present a surface for evaporation that is as small as possible, the evaporation being 84.8 inches per annum in that dry atmosphere. It has also been demonstrated by a long series of tests that the amount of silt carried in suspension by the water of this river is phenomenal, being sufficient to produce a deposit of solid mud that is 1.8 per cent by volume of the total discharge of the river. The reservoir site at Elephant Butte, near Engle, has been chosen with reference to these conditions. The proposed reservoir will be long, narrow, and deep, having a maximum depth of 175 feet, a length of over 40 miles, and a storage capacity of 2,000,000 acre-feet. Sixty per cent of its capacity will hold all the mud that can come down the river in eighty years, but its deep, narrow form will present ideal conditions for sluicing out this mud as opportunity presents itself, advantage being taken at times of an empty reservoir and a flood in the river, or a supply of water from a storage dam above constructed for the purpose.

CONSTRUCTION FEATURES.

At the dam site the bed rock is 65 feet below the present river bed, and the proposed dam will be 255 feet high from bed rock to crest. The crest will be 15 feet above the level of the spillway. A gap 1½ miles west of the dam site forms a natural spillway at the proper level, but this gap is in soft material and will require masonry and riprap. The bed rock is firm sandstone, dipping upstream, and it outcrops on both sides of the river to a height far above the crest level. The dam is to be of cyclopean concrete. There is an unlimited quantity of hard, tough, heavy trap rock near at hand that will be excellent for the broken stone and large bowlders necessary in the structure.

In drawing out the water for irrigation it can pass through water wheels and produce an immense amount of power. The main irrigation canals will also have drops in them that can be utilized for power. The soil in which the canals will be excavated is tight and the silt from the river will make them practically impervious.

It is estimated that the dam, the spillway, the various diversion dams, and the necessary system of canals will cost $7,200,000, or $40 per acre for the land irrigated.

The surveys and tests made by Prof. Charles S. Slichter at "The Pass," a narrow gorge just above El Paso, where the bed rock is 90 feet below the river bed, show that there is practically no underflow at that point, and demonstrate that there is no necessity of going to bed rock with low diversion dams to prevent underflow. Professor Slichter's work also shows that submerged dams from bed rock to river bed, which have been often proposed on this river in order to

bring up the supposed underflow, would be of no use, as there is practically no underflow to bring up. At ordinary stages of river there is very little percolation, except at points where the understratum of silt has been recently eroded by floods or the river has taken a new channel.

IRRIGABLE LANDS.

The 180,000 acres of land to be irrigated are in a long, narrow valley, and the return water from the irrigation of the upper valley can be rediverted on lands lower down the valley. This feature, and other favorable conditions, coupled with the fact that the whole area to be irrigated has an average annual rainfall of 9.3 inches, make it entirely safe to estimate on a duty of 3⅓ acre-feet per acre at the outlet of the reservoir. In other words, it is considered safe to estimate that 600,000 acre-feet per annum drawn from the reservoir will irrigate 180,000 acres of land. This estimate is on average crops, including alfalfa, orchards, corn, grain, vegetables, etc.

Under present conditions the river bed is often dry from four to six months in a year, while disastrous floods come at other times. It is expected that the Engle Dam and the proposed irrigation will change these conditions for the better. The storage dam will hold back all the floods and distribute them over the irrigation period of ten months. The water will be let out as needed and there will be no more disastrous floods below the dam. The river bed will never be dry at any time of year, as the return water from such a large irrigated area will form constant springs along the whole course of the river. Lastly, the supply of ground water for pumping will be greater and more constant than it now is, as the water entering the ground from the irrigated lands will form a constant source of supply.

The valley of the Rio Grande is remarkably fertile. The section under consideration is from 3,500 to 4,000 feet above sea level, and the climate is healthy and delightful. The crop season is long, and the whole region is tributary to El Paso, with its numerous railroads, thus insuring a good market for all products.

INTERSTATE AND INTERNATIONAL QUESTIONS.

This project is peculiarly interesting, not only because it will irrigate so large an area of valuable land, but because it will supply water to settle an interstate question between New Mexico and Texas, and an international question between the United States and the Republic of Mexico.

In making the plans for this Rio Grande project the engineers of the Reclamation Service have recognized the existence of these inter-

state and international questions, and have provided as much water for the El Paso Valley in Texas and Mexico as would have been supplied by the proposed international dam at El Paso, but they have not stated how this El Paso Valley water should be divided between Texas and Mexico; neither have they expressed any opinions as to the sovereign rights of the Territory of New Mexico, the State of Texas, or the Republic of Mexico.

DIAMOND-DRILL METHODS.

By G. A. Hammond.

After a reconnaissance has been made and the feasibility of the project determined, it is necessary to look into the matter of suitable foundations for the proposed dam; or, in the case of a natural reservoir, to ascertain whether its bottom will hold water. For this purpose the diamond drill is employed.

The drill man usually finds that he has arrived before the road makers. In this case provision must be made for hauling the drill to the site of operation. In some cases a hand drill may be transported on pack animals to the reservoir site and lowered over the cliff to the river below.

It is also necessary to ascertain whether the water is fit for boilers. If it is found to be of good quality, the question of fuel is next to be considered. It has been the experience of the writer that good water and fuel are seldom found together. When salty water is found and the contemplated borings are not too extensive, hand drills are employed, water being used only for washing the material out of the bore holes. The motive power is obtained by hand cranks. In hand drilling progress is slower than where steam is employed, but when the cost of fuel and the hauling of water long distances are considered it may be found cheaper.

On most projects hand drills have been used, since, owing to their light weight, freight charges are saved in railroad shipments. In some localities it has been found impracticable to use steam drills on account of the bad water for boilers, and the scarcity of fuel.

In one instance the work was started with hand-power drills, but encountering granite bowlders 26 feet thick, which were too hard and large for hand work, a steam drill was employed to drill and ream the bowlders so that the casing could be put through and driven to bed rock. In another instance the project was 12 miles from water, and much farther from fuel, so that the use of steam drills was impossible.

Diamond drills are now used extensively in all parts of the world. The idea was brought out in the year 1863 by a French engineer, who built and operated the first drill and introduced the carbon to the

professional world. Carbons are found in Brazil. Borts also are found in Brazil and in South Africa. Borts are used in soft rock, but they are not of proper structure for hard rock, as they have a cleavage plane which is not found in the carbon. The cost of bort is about one-fourth that of carbon.

In commencing drilling operations, efforts are made to equip all the parties with casing and rods of standard size, so that if work should not progress satisfactorily on any project, owing to some unforeseen contingency, such as encountering of harder material or finding the depth to rock being greater than anticipated, part of another outfit could be sent in and used with the one already on the project, and in that way a saving in freight charges effected by not having to ship a complete outfit.

The Service equipment has not yet been entirely standardized, owing to the fact that many of the appliances are comparatively new and valuable; but as the objectionable material wears out it will be replaced by standard equipment. For the work now in hand, the standard drill will consist of $2\frac{1}{2}$-inch extra heavy flush-joint casing, $1\frac{7}{8}$-inch drill rod, and $2\frac{1}{16}$-inch diamond bit. The large bit is found to be more satisfactory in the rock encountered in the lava country.

A wooden derrick is employed, which can be trailed behind a wagon; this can be taken down, moved, and set up ready for work in a few minutes. Six or eight hours would be required to make the same move with a steam drill. After the derrick is set up on the plank foundation and guide for casing, the casing is lowered through the hole in the plank, and the rod is put in the casing with a steel X or cross bit on the bottom. Two men take hold of the rope, which passes through a pulley at the top of the derrick and is hooked in a water swivel screwed in the top of the rod, and pull until the rod is raised the distance required by hardness of material; the rod is then let fall and the bit cuts the earth. The rods are hollow, and water is forced through them by means of a hand pump and a hose attached to the water swivel. The earth which has been loosened by the bit is thus forced up and out over the top of the casing. The foreman then clamps a pair of tongs to the casing and by slowly moving it back and forth the casing cuts the side of the bank and follows the bit down.

If a bowlder is encountered, loose material is forced out by the pump, the rods are withdrawn, and a piece of dynamite with exploder attached is lowered by wire to the bowlder, the casing is pulled 2 or 3 feet, and the dynamite is exploded by battery.

When rock is found, the drill is set over the casing, a diamond bit is lowered to the bottom, rods are connected to the drill, and boring is commenced.

Prior to March 1, 1904, some machines were equipped with sle pipe and heavy iron hammers, the method employed being to fo the pipe by driving. The result in hard material was very disastr to the pipe, and several hours were required to pull for blasting to pull out when the borings were finished. By using flush-jo casing and powder, progress is much more rapid, and the casing be pulled in a very short time.

In the drilling department are four steam drills and six hand dri which will be employed when to advantage in the work. The fo men are provided with blank forms of daily and monthly repo which they are required to make out and send to the superintend of borings at Salt Lake City. In that way a very close watch kept on the work, and by referring to the daily reports the super tendent can at any time tell where his presence is most needed.

Parties are made up, when convenient, of a foreman who und stands the driving of casing and the handling of a diamond dr Foremen receive from $90 to $100 per month. The diamond b are set by the superintendent on his regular visits. On projects wh the rock is very hard or where more than one drill is in use, a diamo setter is employed as chief of party, at $150 per month.

MEAN-VELOCITY AND AREA CURVES.

By F. W. Hanna.

FACTORS OF STREAM DISCHARGE.

Inasmuch as the discharge of any river is the product of the cro sectional area and mean velocity for that stage, the most conveni and logical place to seek for guidance in the construction of a d charge curve is in these related functions. It is easier to foll changes in these variables individually than as product. Any stu therefore, that will throw light upon the nature of either of th functions will give valuable knowledge as to the location and natu of the discharge curve. By plotting for varying stages of water t discharges, mean velocities, and areas for any river cross section abscissæ and the corresponding gage heights as ordinates a gene curvilinear relation between any one of these functions and the ga height can be seen to exist. Moreover, where conditions of curvatu slope, cross section, and bed are similar for the same or differe streams, an equal resemblance is noted in all of the above like curv This concomitant similitude of channel and curves indicates clea the source for investigation, but it also indicates the impossibility deriving an exact, and at the same time general, equational law. the four determining elements—(1) channel curvature, (2) chan bed, (3) channel slope, and (4) channel cross section—the probl

of curvature effect may be omitted, as all gaging stations should be so located as to eliminate this element. Of the remaining three elements the area is affected only by the latter, while the velocity, and consequently the discharge, are affected by all of them.

CROSS-SECTION AREA CURVES.

In order to find some approximate law governing the area curve it will be necessary to make some assumption as to the character of the cross-section curve of the stream. To meet this necessity, in order to be strictly accurate, it should be assumed that the profile of any stream cross section consists of a series of arcs of parabolas whose axes are vertical. As the arcs may be taken long or short, and as each parabola may have a different parameter or may be convex outward or inward, and as a straight line is a limiting condition of a parabolic arc, the above statement, while having the quality of being very general and comprehensive, has the merit also of being capable of very close approximation to the actual conditions. From this principle the degree, variability of degree, and direction of the area function may be developed. However, the results are very complicated, and as the intention of the formulæ here developed is for the purpose of showing the impracticability of using them, rather than suggesting them for use, less elaborate and at the same time just as useful information may be obtained by assuming the profile of the river cross section to be composed of a series of short straight lines. Under this assumption the cross-sectional area will be made up of a series of rectangles and trapezoids, promiscuously placed one on top of the other. Since the lengths of the straight lines may be assumed to be very short, no very great error will be involved in formulæ based on this rectilinear assumption.

If C' represents the area below the base of any one of the cross-sectional trapezoids, B the width of its base, θ and φ the complements of the slopes of its sides, x its varying area, y the height of water above its base, and A, $\frac{1}{2}(\tan\theta+\tan\varphi)$, then it may be shown by calculus that the area equations for the rectangular, trapezoidal, and complex channel are, respectively:

1. $x=By.$
2. $x=Ay^2+By.$
3. $x=\frac{1}{2}(\tan\theta+\tan\varphi)\,y^2+By+C.$

In these equations A, B, and C are all positive quantities (excluding cases of overhanging banks) from the imposed conditions in the hypothesis. B, C, θ, and φ are, however, periodical variables in the third equation, changing for each trapezoid. An examination into these equations reveals the following facts: First, that when a channel

is perfectly rectangular the area curve is a straight line; secon that when a channel is perfectly trapezoidal the area curve is a para ola with a horizontal axis extending to the right; third, that when channel is a promiscuous series of rectangles and varying trapezoi the area curve consists of a series of parabolic arcs with varyi parameters and with horizontal axes, which extend to the right, exce that when the expresssion $(\tan\theta + \tan\varphi)$ becomes negative from overhanging bank or banks the direction of the axis is reversed. an overhanging bank is a rare occurrence, the condition will excluded from the discussion hereafter and the expression $(\tan\theta$ $\tan\varphi)$ will, therefore, be positive.

By differentiating the area equations 1, 2, and 3 with respect x and y as variables, there result the following expressions:

$$4.\quad \frac{dy}{dx}=\frac{1}{B}.$$

$$5.\quad \frac{dy}{dx}=\frac{1}{2\,Ay+B}.$$

$$6.\quad \frac{dy}{dx}=\frac{1}{(\tan\theta+\tan\varphi)\,y+B}.$$

In these differential equations $\frac{dy}{dx}$ is the tangent of the angle th any tangent to the area curve makes with the x-axis. Now, sin $dx>dy$ always, this tangent must always make an acute angle wi this axis. Assuming that the gage increments are all taken equal, the area increment receives any sudden increase in value, as it wou where there is a sudden decrease in the slope of the banks, the tange $\frac{dy}{dx}$ becomes suddenly smaller, and there is a corresponding change the direction of the curve to the right. If this increase is due to horizontal line the change in the curve is a sharp angle, if to gradually sloping line the angle will be rounded off. Again, if tl area has been increasing rapidly, caused by one or both banks becor ing more nearly perpendicular, the degree of curvature will sudden be decreased and the curve will become flatter. If at any place the curve the banks become perpendicular, $\frac{dy}{dx}$ becomes constant ai the curve proceeds on a straight line.

By differentiating equations 4 to 6 and multiplying by x there a obtained the following relations:

$$7.\quad \frac{d^2x}{dy^2}\,x=0.$$

$$8.\quad \frac{d^2x}{dy^2}\,x=2\,Ax.$$

$$9.\quad \frac{d^2x}{dy^2}\,x=(\tan\theta+\tan\varphi)\,x.$$

Now, by the theory of curvature, when the expression $\frac{d^2x}{dy^2}x$ is positive the curve is convex toward the y-axis. Inspection of equations 7 to 9 shows that this expression is in every case positive, whence the area curve is always convex toward the y-axis, and, therefore, always concave toward the x-axis.

From the above deduction the following facts concerning the area curve must logically be inferred: The construction of any area curve must be preceded by a careful study of a complete profile of the river cross section. If the cross section is perfectly rectangular or trapezoidal the area curve may be drawn by plotting a few salient points and by drawing through them a straight line or a parabola, as the case demands. However, if the channel is irregular, varying from one form to the other, as is almost invariably the case at all gaging stations, the construction of a reliable area curve can be made only by computing from the elevations of the cross-section profile the area for numerous heights of gage throughout its range of variation, plotting these results and drawing through them the resulting curve.

MEAN-VELOCITY CURVES.

The matter of determining the nature of the mean-velocity curve is not an easy task. The fact that so many varying and doubtful elements, such as roughness of bed, slope, area of cross section, and wetted perimeter, enter into its composition makes it to a large degree indeterminate. The Chezy formula, $V=c\sqrt{rs}$, with Kutter's value for c, is probably the best formula from which to obtain information. Let this formula be written in the following manner: $V^2=c^2s\frac{x}{p}$, where x is the cross-section area and p its wetted perimeter. Now, by substituting the values of x from equations 1, 2, and 3 in this expression, there result the following equations of the mean-velocity curve for the respective conditions of cross section represented by the value of x substituted:

$$10.\quad V^2=c^2s\frac{By}{p}.$$

$$11.\quad V^2=c^2s\frac{Ay^2+By}{p}.$$

$$12.\quad V^2=c^2s\frac{\frac{1}{2}(\tan\theta+\tan\varphi)y^2+By+C}{p}.$$

If s be considered constant, which it is for uniform channel cross section and permanence of flow; if c be considered constant, which is practically the case where changes in gage height do not cause

increase of roughness of bed and where there is permanence of fl and if the increase in p be considered negligible, which may assumed with little error for small rises in a wide, steep-banked stre of uniform depth, then equation 10 is a parabola with its a vertical, equation 11 is a hyperbola with a vertical axis, equation represents a series of hyperbolas with varying eccentricities and u ally with vertical axes, but the axes of which are horizontal wl $B^2-2(\tan\theta+\tan\varphi)C$ is negative. This is equivalent to saying t when the area below any trapezoid base, multiplied by twice the s of the tangents of the angles that the banks make with the verti is greater than the square of the base of that trapezoid the curv reversed and the axis of the hyperbola is horizontal. Owing to properties of these curves and the direction of their axes, if c, s, a p be regarded as constants, it may be expected that the mean-veloc curve will always be concave toward the V-axis when the channel rectangular or trapezoidal, and will or will not be so when the chan consists of a series of trapezoids, accordingly as $B^2-2(\tan\theta+\tan\varphi$ is positive or negative.

Evidently these parabolas and hyperbolas will be considerably m ified by variations in the channel roughness, slope, and wetted peri eter, but the modifications will rarely upset the similitude. T effect of p, since it is always an increasing quantity for increasi gage heights, will be to throw the curve inside of the theoretical cur that is, to make it closer to the velocity axis. The effect of s is b positive and negative in action, as it may either increase or decre for increasing values of y. Its changes depend upon the slope of channel above and below the gaging station and upon the rising a falling condition of the river. Increases in gage height usua increase the coefficient of channel roughness, and, therefore, usua decrease the value of c. Its effect on the theoretical graph, or cur is usually conjoined with that of p. The complicated effects of wet perimeter, slope, and roughness of channel on the theoretical cur make a careful study of the gaging-station conditions absolutely nec sary to an intelligent construction of the mean-velocity curve. Su a curve may be drawn by keeping in mind the theoretical cur here deduced, and by studying carefully the cross-section profile increase in area and in wetted perimeter, by considering the con tion of the banks of the river as to growth of grass and trees and as other obstructions affecting the coefficient of roughness, and by inspe ing the conditions of channel both above and below the station slope influences, and by investigating each measurement to see whet the stream was in a state of permanent flow when it was made.

EQUATION OF DISCHARGE.

Since the discharge of a stream for any stage is the product of the area and mean velocity for that stage, then the equations for discharge become:

$$13.\quad Q=\frac{c\sqrt{s}}{\sqrt{p}}(By)^{\frac{3}{2}}.$$

$$14.\quad Q=\frac{c\sqrt{s}}{\sqrt{p}}(Ay^2+By)^{\frac{3}{2}}.$$

$$15.\quad Q=\frac{c\sqrt{s}}{\sqrt{p}}[\tfrac{1}{2}(\tan\theta+\tan\varphi)\,y^2+By+C]^{\frac{3}{2}}.$$

All of these discharge equations are of a complicated degree, unsuited to practical application, but they serve to show the following important facts: (1) The discharge curve for a rectangular or trapezoidal channel could be determined were it possible to get entirely satisfactory values for c, p, and s. (2) The discharge curve for the irregularly cross-sectioned channel, which is about the only kind used in stream gaging, is a very complicated equation of the sixth degree with respect to Q and y, and contains in addition the varying quantities c, s, p, $\tan\theta$, $\tan\varphi$, B, and C, thus making it impossible to obtain any tangible method of applying it. (3) The first derivative, $\frac{dQ}{dy}$, of equations 13, 14, and 15 shows that the tangent to the discharge curve makes an acute angle with the y axis and is always an increasing function for increasing gage heights unless influenced by unusual fluctuations in s, p, and c. (4) The second derivative, $\frac{d^2Q}{d^2y}$, of these equations shows that the curve is always convex toward the y-axis, and therefore concave toward the Q axis. Fluctuations in s, p, and c are probably never so great as to upset these conditions. (5) The chief and controlling factor in shaping the progress of the discharge curve is the condition of channel.

APPLICATION OF CURVES.

So far there have been considered only the nature and method of construction of the cross-sectional area and mean-velocity curves. It yet remains, therefore, to point out their practical utility. Evidently neither of them would be of much use in and of itself, as there is little need for the determination of river cross-sectional area or mean velocity as ultimate results. Their sole function in the problem of hydrography is as auxiliary components of discharge determination, the discharge being the simple product of these two values. Anything that tends to more accurate results in obtaining these functions increases, therefore, the precision of discharge estimates.

The standard profile and area curve of the river cross section very important for every permanent gaging station. This pro should be very carefully determined by means of soundings at l water and levels up the banks to the high-water limit. The stand area curve can be determined from this standard cross-section prof If the area is computed for various gage heights which have b selected at the critical points in the cross section, a reliable curve be constructed by using the areas as abscissæ and the gage heights ordinates. This curve once constructed for a permanent stat becomes a criterion whereby computed areas obtained at the time measurements may be checked. Also, when on account of high wa or any other hindrance soundings can not be obtained, the depths m be obtained directly from the standard cross section and the area tak directly from the standard area curve. In nonpermanent stati this standard area curve will serve to show the amount of scour or of the channel and the standard cross section will show its locati The standard area curve should be kept on file and every area co putation should be compared with it as soon as it is made. The ve important additional use of the area curve in determining the d charge curve will be mentioned in connection with the remarks that curve.

While the area curve may be obtained immediately for any gagi station, the mean-velocity curve can be constructed only after series of discharge measurements has been made. As soon as a fe fairly well distributed gagings have been obtained the velociti should be plotted and the most probable curve drawn. This cur when kept on file will serve to check subsequent velocity determin tions, and will, therefore, disclose back-water conditions, errors computation, and current-meter defects. When all the yearly mea urements are made, or at any time that it is desirable to make a di charge curve, this mean-velocity curve can be drawn to correspo to the whole data and then used in connection with the area curve constructing the discharge curve.

Owing to the fact that close checks have been kept by the hydro rapher on the area and mean-velocity computations, the dischar measurements will probably make a very reasonably smooth curv and may, therefore, give no further trouble. However, if the mea urements are somewhat at variance with one another, or are not we distributed, it is a comparatively easy matter to draw or extend t mean-velocity curve, which is much less complicated than the di charge curve. By using the standard area curve and the mea velocity curve so constructed a satisfactory discharge curve ma almost invariably be constructed. This discharge curve is obtain by taking the products of the abscissæ of these curves for the corr

sponding abscissæ of the discharge curve for various gage heights. These products should be obtained for every foot or half foot of gage height where the degree of curvature is high, but where the curvature approaches zero these intervals may be increased somewhat.

IMPORTANCE OF GENERAL HYDROGRAPHIC DATA CONCERNING BASINS OF STREAMS GAGED.

By Robert E. Horton.

The publications of the Survey on streams and gagings are largely utilized by persons familiar with and especially interested in some particular stream. They are also used by persons desiring to compare adjacent catchment basins, and gross errors may be and often are committed in attempting to estimate the yield of a drainage basin from that of an adjacent stream or from the yield of the same stream at some point where it has been gaged.

Consider, for example, a stream flowing out of a rocky, forested mountain region and over a broad plain with deep soil under cultivation. Suppose that the stream has been gaged at the foot of the mountains, but it is desired to estimate its run-off at the foot of the plain. A very common method in such cases is to increase the discharge in proportion to the increased drainage area. This method is legitimate in some cases, and unless the person making the estimate had a knowledge of the hydrographic features of the two sections of the basin and of their effect on the run-off and regimen of the stream he might easily infer that such a method was applicable in this case. As a matter of fact, in the case cited it is probable that the use of such a method would result in an estimated discharge at the foot of the plain considerably in excess of the truth. An error of this kind which cost perhaps $100,000, and which resulted in the complete failure of a large project, has come under the writer's observation.

In the reports of the Survey as hitherto published but little data have been given regarding the character of the drainage basins. To persons unfamiliar with the conditions, the fact that gagings at two points on a stream show widely different run-off may be taken as evidence of inaccuracy of the gagings, whereas the real reason for the difference may be in the physical character of the basin.

As the records continue from year to year, conditions in the catchment basins as to forestation, culture, drainage, evaporation, etc., may progressively change, causing a change in the run-off and in the rainfall–run-off relation.

It is important that the state of each drainage basin as regards the above-named features shall be early recorded, so that when changes

occur in the future their relation to the streams may be rationall traced. The physical data which it appears most important t include in descriptions of gaging stations may be classified as follow

(*a*) Shape of drainage basin and description of tributaries- whether sparse or numerous, with branches or without, etc. Th has an important bearing on the flood discharge.

(*b*) Topography. Especially that of the upper reaches of th stream as compared with the intermediate and lower drainage area

(*c*) Soil and underlying rock. The relative location of portion of the area having rock and soil surface, respectively, should b noted. It is also well to know whether the rock is impervious, s slate or granite, or porous and fissured, as sandstone and limeston The character of the soil, whether sand or clay, porous or impervious deep or shallow, moist or dry, should also be noted.

(*d*) Lakes and marshes. Their location, area, and range of varia tion in stage are important as modifying both the flood discharg and the low-water regimen; the existence and extent of flood plain and overflowed areas may also be noted.

(*e*) Culture. The location of the larger forest areas. The pe centage of forest and tilled land. The area of barren rock surfac etc. It is also desirable to state the extent of sodded meadows an pasture lands, as such areas afford maximum evaporation losses.

(*f*) Springs and ground water. The depth of the ground-wate table below the surface. The seasonal fluctuation in level to whic it is subject, and general facts as to the presence or absence of spring It may also be of great value in interpreting gaging records to know whether the topographic drainage basin receives water from o yields water to adjacent basins through ground water.

(*g*) Diversion and storage. Irrigation, drainage, and other art ficial influences modifying the stream regimen should be noted i the records.

(*h*) Rain and snow. The regimen of a stream in a norther climate may differ widely from that of a similar southern drainag basin, owing to the fact that a large part of the northern winte precipitation is held for months as surface storage in the form o snow.

Peculiarities in the distribution or occurrence of precipitation i each locality should be noted, even if details as to the amounts o such precipitation can not be entered into.

If such data as those above outlined are carefully collected an published, the gaging records may become of greatly increased valu and may be safely utilized by those not familiar with the characte of the streams in question.

With such data before him, one could compare the gaging record for streams on the plains with those for streams in the Central State

ind, for example, reasons would at once appear why it is that one iver may yield but 2 inches run-off per year from 15 inches rainfall, vhile another yields 10 inches run-off from an equivalent precipiation.

Conditions such as above described are frequently brought to ight in the reports of the Survey, yet it is not always possible to ind in the published reports the underlying reasons for them. Such physical data as have been outlined form properly a part of the subject-matter of hydrography, and the above notes are given not as a criticism of the work done, but in the hope that they may suggest what auxiliary data are needed to render the stream-gaging records hemselves most complete and useful.

EFFECT OF AQUATIC VEGETATION ON STREAM FLOW.

By Robert E. Horton.

Three principal classes of aquatic plants that influence stream flow nay be mentioned. The first, algæ, has been found to give little rouble, usually growing in small brooks or on rocks in rapids and hallows. The second class, a fine long wiry grass, sometimes called "eel grass," has been observed by the writer, notably in Saratoga Lake outlet, or Fish Creek, in New York. It is accompanied by the hird form, the common dark-green fronded water plant, or eel grass, of New England rivers, in which, however, the fine wiry grass seems o be the chief source of interference.

Fish Creek is a smooth-flowing stream with sandy bed and a very steady regimen, its principal supply coming from Saratoga Lake. It is utilized by important water powers near its mouth. The grass s so scattered that its effect on the stream would at first appear loubtful or unimportant. An examination shows, however, that the stream is filled with swirls and eddies, and its current is very hard to neasure with a meter. As the season advances and the grass growth ncreases the slope and flow become so decreased that cleaning is necessary, and a boat is sent through to cut the grass. Aside from the grass, the conditions are favorable to accurate measurement.

Discharge measurements of Fish Creek, New York, in 1904, showing effect of grass in stream.

Date.	Gage height.	Discharge.	Condition.
		Second-feet.	
August 25	1.46	283	Much grass.
October 5	1.47	311	Some grass.
November 11	1.25	381	Grass mostly gone.

On many Michigan rivers fronded water grass is so common s prolific than a suitable site for current-meter work can hardly found in the course of the stream. Upper St. Joseph River, a f winding, smooth-flowing stream, affords an interesting example. gaging station was established in 1902 at Mendon, at a highv bridge, where apparently measurements could be made with an ex lent degree of accuracy. There is no artificial influence disturb the stream for many miles above or below and no back water fr dams. A descent of over 20 feet slope of stream surface interve between the gaging station and the nearest dam below. The gag located in the open stream channel one-half mile above the bri where measurements are made. It was soon found that there wa wide variation in the discharge at a given stage, and this could o be attributed to the effect of back water from aquatic vegetati growing below the place of measurement.

Measurements made in early spring, before the growth of gr began, showed a maximum discharge for a given stage. It v proposed, therefore, to develop a maximum or normal dischar curve showing the conditions in the absence of vegetable growth the stream. The station has been continued three years, and e season, as the summer advances and the growth of aquatic vegetati increases, the discharge measurements fall short farther and fart from the normal discharge curve.

Ultimately a series of discharge curves will be drawn parallel the normal curve showing "contours" of discharge with varyi degrees of grass obstruction, and in this way an approximate es mate of the summer discharge may be arrived at, somewhat af the method used in estimating discharge of western rivers havi continually shifting beds.

SANITARY REGULATIONS GOVERNING CONSTRUCTION CAMPS.

By M. O. Leighton.

NEED FOR SANITATION.

Sanitation, according to the popular idea, is a science which h no pecuniary utility—that is, the purposes are entirely humanitari and have little or no relation to money values. This idea is erroneo There are phases of the sanitary question which are quite as imp tant from the financial as they are from the purely social standpoi Almost nowhere is this better exemplified than in connection w great construction camps.

The physical condition of the laborer is the measure of his da work. Whether his occupation be active or sedentary, his achie

ments are finally controlled and limited by his relation to physical ills. The difference between the achievements of a person in good and in poor physical condition is a matter of common observation. When this difference applies to a whole community, its total is increased in direct ratio to the number of persons, and in a camp of several hundred workmen it becomes a serious item. It may represent the difference between success and failure in the completion of a piece of work within a specified period, in the character of the work, or in its permanence after completion.

It is only a step from the poor physical condition that is responsible for indifferent labor to the acute illness, during which all productive labor ceases. A general epidemic of acute disease in a construction camp is disastrous. Disease rather than engineering difficulties has been the cause of absolute failure in a few great projects. The earlier attempt at the construction of the Panama Canal is a notable instance. In short, sanitation is one of the vital necessities in construction camps.

Construction camps maintained in connection with the various irrigation projects afford exceptionally favorable ground for the dissemination of disease. There the men mingle more intimately than in almost any other walk of life. Culinary and toilet utensils are used in common, and every other feature favorable to the rapid dissemination of disease is provided. This is true, of course, of all construction camps, but there are in these arid lands additional hazards which no human foresight can provide against. Camps are invariably remote from bases of supplies, and food must therefore be inferior to that which could be provided in more favorable locations, but most important of all is the fact that water is often scarce. The very conditions which make irrigation construction necessary also add to the dangers attendant upon that construction. In arid countries the desire for water on the part of workingmen is far more acute than in humid regions. It is natural that under such circumstances men consider quantity of water rather than quality. Too often there is no choice to be exercised—the one available supply must be used, whether it be good or bad. Thirsty men give little thought to any characteristic of water save that of wetness.

The above considerations make it practically incumbent upon those in charge of reclamation construction to provide against all conceivable conditions or circumstances which might result in an outbreak of disease among the engineers or laborers. To this end it is proposed to incorporate into the specifications of each contract advertised under the reclamation law the following clause:

The use and sale of intoxicating liquor will be absolutely prohibited on the work except under the direction and supervision of the engineer in charge or his agent, and then only for medicinal purposes; and it is furthermore hereby

understood and agreed that the chief engineer may establish rules for sanitary and police regulations in all forces employed under this contract, and should the contractor fail to enforce these rules the engineer may police working gangs and camps and assess the proper proportion of the cost against the contractor, the amount so assessed to be deducted from any sum due said contractor.

SANITARY CODE FOR RECLAMATION WORK.

The following code has been promulgated to govern the location, construction, and maintenance of camps. In drafting these regulations it has been necessary to bear in mind the limitations which prevail in the region covered by the work. The natural conditions and the remoteness of camps from bases of supplies, as well as the widely varying necessities attendant upon the different branches of the work, render it impracticable to attempt to establish and enforce finely definite regulations. In this code it has been the intention to express general principles, with the purpose of having them carry the details by implication.

Camp sites.—Especial care should be exercised in the location of camp sites. They should be placed upon well-drained ground where sun and air may have free access, and as far as possible from bodies of quiescent water, such as bog holes, seepage ponds, and sinks. Low places along river bottoms should be avoided whenever possible, and in case it becomes necessary to establish a camp at any point where the ground-water table is close to the surface each camp structure should be surrounded at its base by a trench of from 1 to 2 feet in depth and an outlet provided for emergency use to drain off water which may collect there.

Camp structures.—Camp sites should always be selected convenient to some source of water supply, but the camp structures should not be placed in close proximity thereto. The slope and nature of the soil should be considered, and no structure should be erected at a point from which effete matter may filter through the ground and infect the water supply.

Lavatory arrangements.—Arrangements should be made for the rapid and complete disposal of water from wash basins, tubs, etc. In the case of permanent camps, a sink should be provided with pipe connection to a covered cesspool, located at a point from which there will be no drainage to a well or other stored water supply. Whenever the conditions are such as to make this arrangement impracticable, the lavatory should be placed at a point similar to that described in the case of the cesspool. Where the nature of the ground is not such as to readily absorb all wash water, an excavation of proper dimensions should be made and filled with loose material to a level with the ground surface.

Water supply.—The water supply for all camps, especially that used for drinking and cooking, should be absolutely free from all suspicion of dangerous organic contamination. Old wells in questionable positions with reference to surface or outbuilding drainage should be avoided, and wherever there are no wells free from such suspicion upon the site of a permanent camp new ones should be sunk at unquestionable points. Whenever it is necessary to erect a camp at which the only water available is open to suspicion or is known to be contaminated with animal wastes, such water should be purified by boiling or by filtration. If the former course is taken, great care should be exercised to maintain at all times a sufficient quantity of stored water which has been cooled after boiling. In many cases where boiling has been resorted to for water purification this rule has not been observed, and the members of the camp, finding no water or only that recently boiled, have been induced to drink raw water. Such an act destroys the value of all previous precautions. Filtered water is far more palatable and generally as safe as that which has been boiled. The Berkefeld or some similar filter is best adapted for such uses. It can be provided in various sizes and should be installed with a suitable container to store filtered water. The pressure should be developed either by pumping direct through the filter or by placing a small reservoir at some point higher than the filter and allowing the filtration process to go on continuously into the clear-water reservoir.

Flies and mosquitoes.—The most important sanitary provision in connection with camps is that of exclusion of flies from cook tents, mess tents, and privy vaults; yet this is the very provision which is most frequently overlooked. According to the report of the commission appointed by President McKinley to investigate into the occurrence of typhoid fever among the soldiers during the Spanish war, almost every outbreak which occurred was due to the lack of sufficient protection against flies. Therefore special care should be taken to exclude flies from all places in which food stuffs are exposed, and, if necessary, in the large camps a man should be detailed to accomplish this purpose.

Mess and cook tents or houses should be provided with screens at all windows, and each door which leads into the outer air should be provided with a vestibule about 4 feet square, constructed in the following manner: The dividing partition and the door between the cook or mess tent and the vestibule should be of wood, as well as the side walls of the vestibule, for a distance of about 1 foot from the dividing wall. The door and walls should be painted black or some dark color. The remainder of the vestibule should be of durable wire netting and the door leading out from the vestibule of the same mate-

rial. With such a provision the flies which enter the outer scr door during the time when people are passing through will be cau in the vestibule and will congregate upon the wire part of the ve bule in preference to the dark-colored wood next to the cook or n tent, and only a very small proportion of the flies entering the ve bule will under such conditions escape into the larger apartment. the cook and mess tents or houses are not built under a common r the passage between the two should be thoroughly screened, and if entrance is made from the passage to the outer air vestibules should provided as above described.

Of equal importance is the thorough screening of privy vaults a vault apartments, for it is from such places that flies carrying up their bodies effete material diffuse throughout the camp an epider by coming in contact with foods. Without proper screening a dis trous epidemic of typhoid may be easily spread through a camp one of the members of the camp, or, indeed, a transient guest, shou be in the prodromal stage of the disease. It is at these times that t discharges are most virulent. Vaults should therefore be built tight material and be provided with a vestibule at the entrance simi to that above described in the case of cook and mess apartments. box of dry earth should be kept in each closet and the contents lib ally sprinkled in the vault after using.

Wherever it is possible to do so sleeping apartments should thoroughly screened, not only for the comfort of the members of t camp, but to protect them from mosquitoes, which transmit the ma rial infection. The genus *Anopheles*, which transmits the malar infection through its proboscis, does not commonly fly about duri the day, but is active at night and should be excluded from sleepi apartments.

Camps should be well supplied with sticky fly paper in cook a mess apartments, and all flies, mosquitoes, etc., should be excluded, far as it is possible to do so, before food stuffs are exposed.

Garbage.—Garbage should not be allowed to remain upon car premises for any length of time, but should be removed as frequent as conditions will allow. While it is necessarily stored upon premis it should be kept in metal containers and protected from flies a other vermin.

Privy vaults should always be placed at a considerable distar from other camp structures, should be kept as dry as possible a should not be so placed that the drainage therefrom will infect t local water supply.

KLAMATH PROJECT.

By J. B. LIPPINCOTT.

INTRODUCTION.

The basin of Klamath River was visited in October, 1903, by John T. Whistler, engineer, who reported on it under date of November 2, 1903. H. E. Green, engineer, also visited this basin in October, 1903, and reported thereon in a communication entitled "Report of reconnaissance of the country lying on either side of the boundary line between California and Oregon in the Klamath and Ashland Atlas Sheets of Oregon, and the Shasta and Modoc Lava Beds Atlas Sheets of California." Both reports were transmitted to the Secretary of the Interior in November, 1903, and were printed in the Second Annual Report of the Reclamation Service. They were preliminary and were considered sufficient justification for a further investigation of this section.

In the latter part of June, 1904, the writer made an extended trip through a portion of the basin of Klamath River and Lost River with T. H. Humpherys, assistant engineer. No extensive surveys had been made at that time, Mr. Humpherys having spent his time in acquainting himself with the general situation. The basin of Williamson River, which lies largely in the Klamath Indian Reservation, has not yet been explored, but it is stated currently that there are large areas of excellent land in this reservation that may be reclaimed. This report is therefore based very largely on general information received from Mr. Humpherys and on a personal reconnaissance by the writer, aided by the topographic maps of the Geological Survey. The data based on the surveys now being made are not yet available.

Permanent gaging stations are being established by Mr. Humpherys at Keno, on Klamath River, at the Horse Fly reservoir site on Miller Creek, at the Clear Lake reservoir site on Lost River, a gage rod and evaporating pan in Tule Lake, near Merrill, and a gage rod in Klamath Lake, near Klamath Falls. Measurements of the flow of Link or Klamath River at Klamath Falls will be continued. Mr. Whistler's gaging station on Lost River, in Langells Valley, will be abandoned, as will the gaging station on Lost River at Olene.

GENERAL LOCATION.

The general location is in Klamath County, Oreg., and in Modoc and Siskiyou counties, Cal. The State line to a singular extent divides this basin between the two Commonwealths. For instance, the Clear Lake reservoir site lies in California, but the water impounded therein can best be used in Oregon. The Horse Fly reser-

voir site is situated in Oregon, and this water can best be used Oregon. A diversion conduit from Upper Klamath Lake will se lands both in Oregon and California. The falls of Klamath Ri are in both California and Oregon, and this power can best be u for the pumping of water onto lands in California. Klamath Ri is navigable in a portion of its course and is so used commerciall Upper and Lower Klamath Lakes are commercially navigable a are cut in half by the State line. Tule Lake is navigable, but is used only to a slight extent; it is cut by the State line. We the fore have an interstate situation, both as to water supply, power, a irrigable lands.

This immediate region has no railroad, the nearest station bei Pokegama, from which a stage drive of some 24 miles is made Keno, from which point Klamath River may be navigated by mea of a gasoline boat to Klamath Falls, which is the county seat Klamath County. Two railroads are now being projected into t region, one from Pokegama and the other, known as the Weed roa from California. Both these railroads are built primarily for lu bering purposes.

DRAINAGE.

The principal streams of the Klamath basin are Wood, Willia son, Sprague, and Lost rivers. The drainage is quite singular. L River at present does not flow into Klamath River, but into T Lake, which has no outlet.

Klamath River.—Wood and Williamson rivers are the two pri cipal tributaries of the Klamath. Wood River is fed by some ve large springs, the water supply apparently coming in large pa from the country around Crater Lake; Williamson River drai the region northeasterly from Klamath Lake.

These streams flow into Klamath Lake, which covers 67,220 acre and, if the marginal swamp lands are included, 94,000 acres. T river is therefore regulated by this large area of lake and swam From Upper Klamath Lake the stream falls abruptly about 56 fe and is called Link River. At Keno the lower rapids of Klamat River begin. Link River also supplies Lower Klamath Lake, whi covers 29,400 acres with water and 88,300 acres of water and margin swamp. The lower lake acts as an additional regulator, and t fluctuation in river height at Keno probably does not vary over or 3 feet.

On October 25, 1903, Klamath River was measured at Klamath by Mr. H. E. Green at its low-water stage, and its volume fou

[a] An act of Congress approved February 9, 1905, authorizes the Secretary of t Interior to interfere with these navigable waters by constructing irrigation wor Similar permits have been granted by the States of California and Oregon.

to be 2,000 second-feet. It was stated at the time that the river was lower than at any previous time for twelve years. The low-water flow of Link River in 1904 was 1,773 second-feet. Upper Klamath Lake may be used as a storage reservoir, if desirable.

The elevation of Klamath River near the Southern Pacific crossing at Klamathon, according to the topographic sheets of the Geological Survey, is less than 2,200 feet. The elevation of the river at Keno is 4,086 feet, as determined by levels run from Klamathon, which indicated a fall of about 1,900 feet in a distance of 40 miles. Near the mouth of Falls Creek there is a drop in the river of 400 feet in 2 miles, as indicated by the topographic map on the Shasta quadrangle. With a low-water flow of 2,000 second-feet, this 400-foot drop would develop 91,000 theoretical horsepower. Beginning at a point about 6 miles below Keno the map indicates a drop in the river of 800 feet in a distance of 10 miles—sufficient to produce 181,000 theoretical horsepower, with a flow of 2,000 second-feet. From this it will be seen that the opportunities for power development on the river are very great, and it will be shown later that there is the possibility of using this power for irrigating arid lands.

It appears to be feasible to make an excavation near Keno in the channel of the river at the head of the rapids, where the river drops 60 feet in a short distance, by means of which the water can be drawn off of the marshes surrounding Lower Klamath Lake, as well as from Lower Klamath Lake itself. This difference in elevation probably could be made sufficient so that the flood waters of Lost River which are not impounded in the reservoir sites on Lost River could be turned into Klamath River and away from Tule, or Rhett. Lake. The advantage of such a proceeding will be treated later.

Lost River.—Lost River is an interstate stream, which flows to a material extent through Clear Lake. Horse Fly reservoir site, on Miller Creek, tributary to Lost River, has a drainage area above it roughly estimated at 200 square miles. Its elevation is 4,792 feet. The basin is fairly well timbered and apparently has a fall rainfall and winter stream flow. The reservoir basin is very flat and swampy and it is estimated that the area of the valley is about 3,500 acres, and that a dam 50 feet high would give a capacity of 100,000 acre-feet. The river flows through a narrow canyon of basaltic rock at the dam site. The land in this reservoir site is largely public and has been withdrawn for a reservoir. The site is of very substantial importance.

Clear Lake reservoir site is situated on the southern branch of Lost River, and above Clear Lake the stream is known as Willow Creek. The drainage area of Willow Creek, above Clear Lake dam site, as

obtained from the topographic sheets, is 577 square miles. The a of this lake as shown on the topographic sheet is 12½ square mi or 8,000 acres. A dam 40 feet high at dam site below the l would probably hold half a million acre-feet. The dam site in a canyon of volcanic rock. Apparently there are excellent sp way opportunities and probably the dam could be best construc of earth and loose rock. There is a very pronounced public opini to the effect that the principal supply for Lost River comes do Willow Creek. The grades into Clear Lake are very singul Willow Creek in flood discharge overflows into Clear Lake, but the same time a large portion of this water passes down Lost Riv When the creek falls Clear Lake begins draining into Lost River a discharges through its intake channel. The area of Clear La according to land-office surveys, is 9,200 acres. The area of adjac swamps, according to survey, is 15,000 acres. The drainage ba above the lake is covered by a sparse growth of pine trees. T elevation of the lake is 4,533 feet, according to the contour ma The rise of the lake during the past winter would indicate an infl of about 150,000 acre-feet additional to the discharge of Lost Riv which was continuous during the inflow period.

Lost River discharges into Tule Lake, the area of which is 90,0 acres. During the past winter the lake had a net rise of 7 feet, in cating an inflow of 830,000 acre-feet. The past winter, howev was one of unusual rainfall. The evaporation in this region believed to be about 3½ feet. As this lake maintains an area of abo 90,000 acres, this would indicate a mean annual net flow of L River of 315,000 acre-feet. This agrees with a statement as to t usual annual rise of Tule Lake. There is the opportunity, both Clear Lake and Horse Fly Valley, to hold over water from wet dry years. It would seem reasonable to expect that 200,000 acre-fe annually might be obtained from these two reservoir sites. The wat from these reservoir sites would naturally be used on Langells Valle which contains about 12,000 acres of irrigable land; Poe Valley, co taining 10,000 acres; Swan Lake Valley, 30,000 acres; Alkali Valle 20,000 acres; 72,000 acres in all. These areas are gross and on roughly approximate, and probably will be increased by a detail investigation. It would seem reasonable, however, to consider th these two reservoir sites can irrigate all the underlying agricultur lands in the valleys named. There is practically no public land Poe Valley, some public land in Langells Valley, and quite a lar amount of public land in Alkali and Swan Lake valleys.

As previously stated, the flood waters not impounded in Horse F and Clear Lake reservoirs could be diverted into Klamath Riv and away from Tule Lake.

IRRIGABLE LANDS.

Butte Valley.—Butte Valley is in Siskiyou County, Cal., adjacent to the northern line of the State. It is roughly estimated that it contains over 100,000 acres of agricultural lands, including some 10,000 or 15,000 acres of Government land in the southern portion. The elevation is about 4,200 feet, between 150 and 200 feet above the level of Lower Klamath Lake. Butte Creek and Antelope Creek flow into this valley. The midsummer water supply, however, is quite small and is used for irrigation. There would be an abundant water supply for pumping from Lower Klamath Lake, and a great abundance of power obtainable from Klamath River for lifting this water into Butte Valley. The question as to whether it is commercially feasible to do this is not yet ascertained, but the withdrawals of public land along Klamath River for the purpose of generating power pending this investigation are believed to be justified.

Tule Lake.—Tule, or Rhett, Lake has an area of 90,000 acres, supplied from the inflow of Lost River. Tradition states that at times in the past the lake has been almost dry, that teams have crossed over very considerable portions of its area, and that sagebrush stumps are found in the lake. If Lost River water can be mostly impounded in reservoirs and the surplus diverted into Klamath River by lowering the outlet of the river at Keno and by throwing a levee across Lost River, there practically will be no other supply into Rhett Lake, and with an annual evaporation of 3½ feet, it is believed that the lake would rapidly shrink in area and uncover a large area of land. It is a fresh-water lake. This lake is interstate and navigable, but is only slightly so used. The margin of the lake is meandered by the land office. If the lands that are uncovered are public lands that could be disposed of under the reclamation act, they could be very easily irrigated by means of a diversion canal, either from Klamath River or from Lower Klamath Lake. This is a subject that will require legal opinion. Tule Lake is an interstate navigable lake, and could only be drained by Congressional permission. In January, 1905, the States of California and Oregon, by legislative act, relinquished to the United States any right or title that they might have had to lands in these lake beds, with a proviso that these lands are to be disposed of under the terms of the reclamation act.

Lower Klamath Lake.—Lower Klamath Lake has a water surface of 29,400 acres and a swamp and water surface of 88,300 acres. If the outlet from the lake at Keno can be lowered, as previously suggested, the greater portion of this swamp land can be drained, and

probably a large portion of the lake bed itself. This lake is int state and navigable, and used commercially for navigation. T situation is a duplicate of that at Tule Lake, and if these lands c be drained they can be readily irrigated from Klamath River. T swamp lands are all in private ownership, title having been co veyed by the State.

The areas of the beds of these two lakes that might be uncover as suggested, are not definitely known as yet, and are being det mined by survey, but it would seem within reasonable limits to s that there might be from 50,000 to 75,000 acres of public lands reclaimed.

Klamath Indian Reservation.—Klamath Indian Reservation h not yet been investigated, but it is reported that there are lar areas of irrigable lands therein, and this will be made a subject future study. Particular attention is called to the fact that t State of Oregon has a claim pending in court for the swamp lan shown as the Klamath Marsh on the Klamath quadrangle, whi lands are in the Indian reservation.

Land withdrawals.—It was deemed advisable to withdraw, least temporarily, all public lands in the Clear Lake and Horse F reservoir sites, the public lands along Klamath River, and suc townships as contained public irrigable lands. If the beds of the navigable lakes are public lands, as is believed to be the case, it wi probably be possible to reclaim 100,000 acres of public land in add tion to over 150,000 acres of private land under this project.

Summary.—The following is a very rough estimate of the gro irrigable areas:

Irrigable from Clear Lake and Horse Fly reservoirs.

	Acres.	Acr
Langells Valley	12,000	
Poe Valley	10,000	
Swan Lake Valley	30,000	
Alkali Valley	20,000	
Total		72,0

Irrigable from Klamath River.

Between Klamath and Merrill	60,000	
From Merrill to Carrs	10,000	
Bed of Tule Lake	50,000	
Bed of Lower Klamath Lake	20,000	
Total		140,0
Butte Valley, irrigable by pumping		100,0
Total		312,0

The water supply is believed to be adequate for this irrigation.

EXISTING CANALS.

A canal has been constructed from Lower Klamath Lake, near the State line, for the irrigation of the north shore of Tule Lake. This is the largest canal in the district. Its manager is Mr. Frank Adams, post-office address, Merrill. The writer has talked with Mr. Adams and with other owners of the canal, and they state that all they wish is water for their lands, and that they will be pleased to have the Government enter this field and to turn over their canal systems to it.

Another canal, diverting between 600 and 1,000 inches of water, near Klamath Falls, irrigates some 5,000 or 6,000 acres of land between Klamath Falls and Lost River. The ditch was constructed some years ago, and has passed through bankruptcy; the United States has an option for its purchase for $50,000. There are also one or two small irrigation ditches in Poe and Langells valleys.

About January, 1904, the Klamath Canal Company was organized for the purpose of constructing a canal from Upper Klamath Lake toward Tule Lake, paralleling the largest existing canals in this region at some 10 or 15 feet higher elevation. W. K. Brown is manager. The company entered into contracts to furnish water to land owners southeasterly from Klamath Falls and along the existing canals at $10 an acre, with $1 per acre annual rental. Their water contracts are severe. At present this corporation is constructing a tunnel 4 by 7 feet in section out of Upper Klamath Lake, the intention being to widen this tunnel to such dimensions as may be required by the contracts that are ultimately entered into. They have purchased some land and succeeded in signing up for water for about 29,000 acres of land, their field of operation covering some 60,000 acres. This canal company at present is very active along promotion lines, and is working a large force of men on the tunnel in question. They began work about August 1. They express very great dissatisfaction and regret over the fact that the Reclamation Service is making investigations in this section, as it will interfere with their programme, and have endeavored to have orders issued by the Secretary of the Interior to suspend the surveys. The principal men of this region, however, outside of this corporation, seem to be of the opinion that public irrigation works are desirable, and have presented numerous petitions to this effect to the Service. The Reclamation Service will not proceed unless the people of the region desire it. The withdrawals made were only for the purpose of giving the Reclamation Service an opportunity of investigating the country sufficiently to determine whether there was any occasion for the construction of public works. These withdrawals were considered necessary, as the

Klamath Canal Company were filing on streams and endeavoring to file on the Horse Fly and Clear Lake reservoirs, which filings, if perfected, might prevent the Federal Government, or, for that matter, any other irrigation enterprise, from doing business in this region.

It would hardly seem reasonable that the Reclamation Service should have stood aside for a corporation that was not irrigating an acre of land, and that did not have a mile of ditch or canal constructed, and leave to this corporation the reclamation of over 300,000 acres of land lying in 3 counties and 2 States, the source of water supply being both interstate and navigable, and a large part of the land being in the beds of navigable lakes.

TRAINING ASSISTANTS IN OFFICE AND FIELD.

By G. H. Matthes.

That much of the future success of the Reclamation Service depends upon the ability of its engineers and the manner in which the younger men are trained hardly needs to be pointed out. The question which arises in this connection may be propounded as follows: When and to what extent are we to train our men? While the question is not one which admits of a direct answer, and I would not presume at this time to outline a definite procedure, I desire to review a number of points of particular interest in this connection, drawn from my personal experience and observation.

In the organization of the Reclamation Service a vast corps of men have been taken into the Service, most of whom have received a more or less technical training, some being graduates of universities and technological schools, while others are self-made engineers. It may be assumed from their statements of past experience and from the civil-service examinations which these men have passed that they are qualified to do certain kinds of work. The examination papers furnish little or no clue, however, as to ability and personal merits, and when the men enter the Service they can only tentatively be assigned to such work as they seem to be best fitted for. The next step is to bring out their best qualities, advance them, and make better employees of them. From my personal observation I find that the younger men are most easily molded into something better. They are generally quick to grasp new things and adapt themselves to their new environment with its many rules and regulations. Their schooling, if it has been of the modern university standard, enables them to study out problems and new features in a scientific manner, independent and unconscious of the routine and stereotyped methods of older engineers.

With the older men it is a different matter. Previous experience gained elsewhere and the practice and methods with which they have been in contact for years have caused them to form definite conclusions as to engineering and business practice, as well as a multitude of preconceived ideas regarding the new work before them, which in many, though not all, cases may be regarded as obstacles preventing them from readily falling in line and adjusting themselves to the routine of the new order of things. That their past experience has been in many ways of great value to the Reclamation Service is not here denied. The fact remains, nevertheless, that, other things being equal, the younger the man the better the chances for developing him into an engineer specially adapted for our particular class of work. To repeat an old saying, "It is easier to learn than to 'unlearn.'"

It sometimes happens that an engineer who has entered the Service and previously had a good experience in a certain class of work is placed on similar duties in the Reclamation Service as a natural outcome of his peculiar fitness for that particular work, and that he is given practically no opportunity for branching out in other directions and generally broadening himself. Conspicuous cases of this kind have come under my notice, and they are usually to be ascribed to inevitable conditions which can not be readily remedied except as opportunity offers. The men in such cases have not been able to improve and advance themselves, and promotion has, of necessity, been slow, or has not been made. Cases of this kind are unquestionably a detriment to the Reclamation Service as well as to the individuals themselves.

In order that an employee may be promoted and become a valuable man to the Service it is necessary that he should be trained to do more and more advanced work, and be given opportunity for study and self-improvement. The Reclamation Service is not a technological institution, nor are the principal engineers teachers dispensing free information. Yet to train men right requires personal attention. Those who are in charge of work and in more or less immediate contact with the younger men have a duty to fulfill in this respect which requires thought and judgment. Probably among the first things that the new man turns his attention to is the book of regulations, and it may be said here that it is beyond the average human intellect to remember regulations from the mere reading of them and that practical application is after all the only means for impressing them permanently on the mind. The sooner new men are made acquainted with matters pertaining to vouchers, reports, etc., through actual practice the sooner will they become proficient in the use and knowledge thereof. I find that after a man has spent

some time on the book of regulations and the large number of circulars issued by the Washington office they cease to make an impression on him unless, as stated above, he has occasion to keep up his interest through practical application.

In a measure it is, therefore, useless to try to make the younger men familiar with all regulations, and only the more important ones should be brought to their attention as occasion requires. Well-equipped bulletin boards posted in conspicuous places in the western offices and kept up to date will be found great aids in this direction. Regulations of local importance, issued by the district engineer, can also in this manner be brought to the attention of the men, who should be held responsible for reading and noting all matter so posted. A place on the bulletin board should be reserved for press bulletins and weekly programmes.

Text-books, reports of the Reclamation Service, Water-Supply Papers, special reports, and plans prepared for other projects are very useful and constitute the best information that can be brought before our men. But here will be found a serious stumbling block; the men as a rule have not time to study or read to any great extent, this being especially true of the field men. At the close of a long day's work out of doors they are tired, and after supper no desire is manifested to settle down to hard studying. Men who are out on surveys during six months of the year do not improve much intellectually, excepting in so far as the details of their field work is concerned. It is further true that the more men are brought together in camps, socially, the less the opportunity for study. This is a serious drawback to field work and camp life.

The men who are located at points where offices are being maintained have a great advantage in this respect over the field men, and get much opportunity for studying. This is particularly true of the Washington office, where the library, map collections, magazines, and office files present an almost inexhaustible source of information, and where the young engineer possessed with ambition and love for his profession will find study a pleasure. This pleasure, or more strictly speaking opportunity, is denied the men working in the field, and there exists, therefore, a necessity for shifting the latter from the field to the office and back again whenever the nature of their work and circumstances warrant this. Many of our field men who have never served an apprenticeship in the Washington office have a most hazy conception of what constitutes a Government office, its relation toward the public on the one hand and toward Congress on the other. Their lack of knowledge of office routine, insight into administrative work, and the necessity for system and so-called "red

tape" sometimes borders on blissful ignorance. Yet these are matters that should be instilled into men from the start, as they constitute the kind of knowledge which can be assimilated by small degrees only.

Doubtless it devolves upon the district engineers, who are constantly in touch with the younger men, to train them and in a measure to teach them. They are in a position to tell the men what books to read, what authorities to consult, and, last but not least, they can lay out the work of their assistants in such a manner that they may gradually be made familiar with a variety of duties, broadening their minds and rendering them more and more valuable to the Service. It appears to me that district engineers should have in mind the education of their assistants if for no other reason than that upon their recommendation depends in a large measure the promotion of the assistants. Briefly stated, the district engineer should be best fitted to judge of his assistant's capacity and ability by knowing what studies that assistant has been pursuing in connection with his regular work.

At Lawton, Okla., I made it a point to install electric lights sufficient to enable my assistants to study evenings. The various text-books owned by the different men formed an excellent nucleus of a library of engineering knowledge. Several of the irregular employees have taken up courses of study in engineering subjects with leading schools of correspondence, and I have always encouraged work of this kind as being to the best interests of all concerned. Even with these advantages the amount of studying done after hours has been comparatively little, and during the hot summer evenings it was practically nil. In summary it may be said that the average man can not study unless he is in the right mood, and to obtain the latter the conditions should be favorable, in providing which the district engineer can be instrumental to a large extent. Much will depend on local conditions, of course, and I realize that my remarks as drawn from my own observations may not be applicable in all cases and may require modification.

In conclusion, I desire to submit for consideration and criticism a list of text-books which, it is believed, should be owned by every engineer or assistant in the service who aspires to a higher position.

Useful text-books for engineers.

Trautwine's Civil Engineer's Pocket Book.
Searle's Field Engineering.
Carnegie's Hand Book.
Wilson's Topographic Surveying.
Merriman's Hydraulics.
Baker's Masonry Construction.

Baker's Roads and Pavements.
Folwell's Sewerage.
Folwell's Water Supply Engineering.
Molitor and Beard's Manual for Resident Engineers.
Vega's Logarithms.
Wilson's Irrigation Engineering.
Weston's Tables of Friction of Water in Pipes.
Johnson's Engineering Contracts and Specifications.
Merriman and Jacoby's Text-Book of Roofs and Bridges.
Allen's Railroad Curves and Earthwork.
Frizell's Water Power.
Foster's Electrical Engineer's Pocket Book.
Patton's Foundations.
Johnson's Materials of Construction.
Byrne's Inspection of Material and Workmanship.

NECESSITY OF DRAINING IRRIGATED LAND.

By Thos. H. Means.

The necessity of draining agricultural lands has long been felt, in many places drainage is extensively carried on. Drainage is rule rather than the exception on the better farms in the States Ohio, Indiana, and Illinois. In irrigated districts practically drainage works have been built, and the necessity of drainage is generally recognized, despite the loss of large areas of land by se age waters and rise of alkali in many places.

Aside from the necessities of drainage, which every engineer app ciates, there are a number of reasons from the standpoint of plant which are not so well known. As we are building works irrigation of land on which to grow plants, it is well to consi how these are affected by drainage and what reasons they adva for drainage.

The majority of plants in common use by American farmers h been developed from wild species through long years of select the most desirable individuals. Agriculture has developed on lands, using the term in contradistinction to swamp lands. V few plants can grow with roots in standing water; the greater num attain their most satisfactory development in soils containing a m erate amount of moisture. This quantity of water varies from 5 cent to 30 per cent by weight, depending upon the character of the s This amount never exceeds that which will be retained by a w drained soil; all moisture remaining above that which will dr away is in excess of the requirements, and is detrimental to pro plant growth.

Plant roots need water and air. If either is excluded, or if eithe

difficult for the plant to obtain, growth is checked and there is likely to be a shortage in the harvest. Roots not only need air, but they need fresh air, and consequently ventilation is desirable. All of us know how difficult it is to ventilate a room from one opening. Drainage provides a second opening and permits the more ready "breathing" of soils and the consequent ventilation of the spaces around roots.

Bacteria play an important part in the growth of plants by living in the soil around and on roots and assisting in the chemical changes which are needed to prepare the plant food for the roots. In many cases the bacteria do not seem necessary to plant growth; in other cases their presence and activity is essential. The best-known example of this is in the case of the leguminosæ, a family of plants including alfalfa, clovers, beans, peas, peanuts, locusts, vetches, and others. Bacteria which develop on the roots of the leguminosæ have the faculty of obtaining nitrogen from the atmosphere and combining it in such form as to be available for the higher plants. The importance of these minute organisms can not be overestimated, for nitrogen is the most costly and the least abundant of the essential plant foods in soils. To foster these helpful organisms, therefore, becomes the duty of every farmer. The nitrifying organisms can only live in an aerated soil. Stagnant air or excess of moisture prevents their forming the nutritive nitrogen compounds and frequently encourages the development of other species of bacteria, which act in the opposite way and decompose nitrogen compounds, liberating the nitrogen.

Wet soils are colder than those well drained, for the evaporation from the surface uses up heat and the presence of an excess of water filling the soil pores prevents the circulation of warm air. Cold soils retard germination of seed and prevent the most rapid growth of plants. Drainage removes the excess of water, allows the pores to drain, and permits a more rapid warming of the soil in the spring. Experiments have shown drained soils to be as much as two weeks in advance of adjacent undrained fields.

Aside from these general reasons for drainage, there are in the arid regions other important reasons why soils should be drained. It is almost impossible to apply exactly the right amount of water. If too much is applied, the subsoil becomes saturated unless the natural drainage is perfect. If the natural drainage under one field is good, the water drained away from it may run underground to rise at the surface of some field lower down.

In its movements water dissolves and carries with it alkali, which accumulates where the water evaporates. Drainage lowers the water surface so that it can not evaporate at the surface of the land and

deposit alkali; drainage removes from each field the excess of water applied and prevents drainage to lowlands by those higher up.

Besides the actual moving and concentrating of alkali salts, which so often occurs in undrained fields, there is brought about a very harmful chemical change. Stagnant soils poorly aerated frequently become charged with black alkali or sodium carbonate. Drainage and aeration produce the opposite reaction and change the sodium carbonate to less harmful salts. It is frequently possible to reclaim black-alkali lands by simple aeration and removal of the excess of water. Where the formation of black alkali has gone on for a great length of time, drainage alone can not speedily accomplish the reclamation, but must be assisted by washing out the excess of soluble matter.

Many other reasons why irrigated lands should be drained can be given, but these are considered the most important. One familiar with western soils and agriculture needs no further reasons to show the value of drainage.

ALKALI SOILS.

By Thos. H. Means.

The term "alkali" or "alkali soils," as commonly used in the Western States, has reference to soluble matter within the soil and does not refer to the chemical properties of the soluble matter. The choice of the term is unfortunate, as many think it refers to soils which are alkaline in a chemical sense. Thus frequently one is told that the soil contains not "alkali," but common salt, while as a matter of fact the majority of western farmers include all soluble salts in the general term "alkali."

OCCURRENCE OF ALKALI.

There are two kinds of alkali popularly recognized—black alkali, consisting solely of sodium carbonate (washing soda, or sal soda), and white alkali, including all other soluble salts found. The most common white-alkali salts are sodium chloride (common salt), sodium sulphate (Glauber's salt), sodium bicarbonate (baking soda), magnesium sulphate (Epsom salt), magnesium chloride (bittern). Small quantities of potassium and calcium salts are found, but the more abundant calcium salts are relatively insoluble and the amount which is in solution at any one time comparatively small.

This soluble matter occurs in western soils as the direct result of rock weathering. In many places the soluble matter has been carried by water and accumulated in poorly drained spots. In other locali-

ties the alkali is distributed throughout the soil where it originated. Practically all rocks contain small amounts of sodium, potassium, and magnesium, held in insoluble form in the mineral constituents. The weather influences acting upon the rock bring about disintegration and decomposition or a change in the chemical arrangement of the atoms. Certain portions of the minerals during decomposition yield soluble salts. These are taken up by percolating waters and in the humid States almost entirely removed. In arid regions the amount of percolating water is so small that the soluble salts are left in the soil, while in many cases that which is removed from its place of formation is deposited by the evaporation of the waters in some stream channel or alkali-lake bed.

EFFECT UPON PLANTS.

To have any effect upon plant growth matter must be in solution. One frequently hears the statement that there are deleterious substances in a soil which are not soluble and which can not be removed. Fears on this score are groundless, for a plant can only absorb through the roots materials dissolved in water. Our study of the action of alkali salts within a soil is therefore limited to that portion soluble in water.

Certain soluble salts are poisonous to plants in very small quantity. In this respect they act very much as poisons do toward animals in bringing about some physiological change which results in disease or death. Copper salts have this action. Fortunately they are almost unknown in waters or soils in agricultural communities, though cases have been known where water coming from mines, mills, or chemical works was harmful to both plant and animal life.

Other salts, those commonly occurring in western waters and soils, are deleterious to plant growth only when present in appreciable quantities. The effect upon plants of matters in solution is well known to all who have studied western agriculture. The mode of action of these salts is unfortunately not so well known, and the principles can therefore be stated only in the most general terms. As is known, the roots of plants are made up of cells whose walls are absorptive of water and to a limited degree of mineral salts in solution. These walls are what is termed "semipermeable"—that is, they are enabled to absorb water and small quantities of certain salts, but can not absorb other salts. The solution inside a cell must be of greater concentration than that outside in order that absorption of the water can occur; so it follows that when the soil moisture or water around the root cells is of greater concentration than that inside, the cells can not absorb the moisture and the plant actually dies. This fact can be easily illustrated by immersing the roots of a growing

plant in a strong 5 per cent solution of common salt. The plant v in a few minutes wilt; the roots, instead of taking up water, actu give off water. Some such action as this occurs in soils. If alkali spot in a field is observed, there will be seen certain pla stunted, hardly alive, others yellowed and looking as though wa was scarce and they were suffering from a drought, while a li farther away from the edge of the spot plants are flourishing.

There is a great range among individual plants of one species a between different species. Certain plants, such as sorghum, su beets, date palms, and pears, have the faculty of withstanding lar amounts of alkali salts in solution than others and are for that rea termed "alkali resistant."

Sodium carbonate, or "black alkali," has a different action to t of white alkali. This salt is alkaline in a chemical sense, or caus and corrodes the vegetable tissues. Its action is most severe at t surface of the ground, where it corrodes the bark, killing the plants much the same way a forest is destroyed by "ringing" the trees.

AMOUNT OF ALKALI ALLOWABLE IN SOILS.

The amount of alkali which is allowable in any soil varies with t soil, the plant to be grown, and the kind of alkali. To state acc rately, therefore, the amount allowable all of these factors should known. In practice the most general figures are given, with alfal as the basis—that is, the soils are graded according to their ability grow alfalfa. The following figures may be given:

Allowable percentage of alkali in soils.

Effect.	White alkali salts, principally sulphates.	White alkali salts, principally chlorides.	Black alka (sodium ca bonate).
	Per cent.	*Per cent.*	*Per cent.*
Good for all crops	0.0 –0.50	0.0 –0.25	0.0 –0.
Good for alkali-resistant crops	.50–1.00	.25– .60	.10– .
Too alkaline for crop growth	1.00– +	.60– +	.20– -

Upon this basis maps showing the various grades or degrees alkali are constructed. These maps can of course have only the mo general interpretation, as soils in the field are so spotted in charact that complete detail is impossible.

In the classification of lands, as pursued by the Reclamation Ser ice, soils are examined in the field to determine the amount of alka present. The total amount of alkali is determined by taking t electrolytic resistance of a portion of the soil saturated with wat

Pure water is almost a nonconductor of electricity, its conductivity depending upon the amount of soluble matter present. Thus by knowing the conductivity of the soil and the effect of the solid soil grains it is possible to determine approximately the per cent of alkali. This method is admittedly not exact, but by using certain easily applied corrections the results are sufficiently accurate for all practical purposes. One especial advantage of this method is that the results are arrived at on the field.

The amount of sodium carbonate or black alkali and the amount of chlorides present can also be determined by simple methods in the field. A measured sample of the saturated soil is mixed with a measured quantity of water and an aliquot part filtered of the suspended matter. The amount of sodium carbonate is determined by dropping in tablets containing sodium acid sulphate. The presence of sodium carbonate is indicated by the purple color which appears on adding a drop of phenol phthalein; the tablets are added until this color disappears. In a similar manner the amount of bicarbonate and chlorides is determined.

MOVEMENTS OF ALKALI IN SOILS.

In virgin soils the bulk of the alkali salts occur at about the maximum depth penetrated by moisture. This depth varies somewhat with the kind of soil and the amount of rainfall. Where the land is, however, very wet during a portion of the year, as in undrained swales and lake beds, the salt is brought to the surface and left as a white crust.

The alkali hidden below the surface is the most dangerous kind, for it is frequently hidden so as to be unsuspected. In many places it is down 10 or 12 feet below the surface and comes to the top only after a long series of years. In the early days around Fresno, Cal., there were few or no evidences of alkali on the surface of the land; water was from 60 to 100 feet below the surface. After a number of years of irrigation the water rose until now under many thousands of acres water is within 3 to 6 feet of the surface and during parts of the irrigating season closer. In its rise the small amounts of alkali scattered through the subsoil were accumulated and brought to the surface and left there by the water brought to the surface by capillary action. In many other districts the same story may be told.

The alkali in a soil can move only when in solution, and so its movements are governed and measured by the movements of the soil moisture. Two kinds of movement occur in a soil, movements caused by gravity and movements caused by surface tension (capil-

lary movements). Gravity movements occur only when a soil c tains an excess of water above that required by plant growth. movement occurs in the larger pores, root holes, insect, and ani burrows and to a much smaller extent through the small pore sp which make up the bulk of the soil. It is a well-known fact t almost any soil can be made more impervious by puddling. T can be explained by saying that in the puddling the large grav pores are broken up and only the smaller capillary pores are left.

To illustrate the movements of water and alkali in a soil, let assume a typical case of a soil filled with both gravity and capill spaces. Irrigation water is applied at the surface. The water si in the soil, going most rapidly down the gravity spaces and being c ried laterally into the smaller pores by capillary action. With th once filled all motion in the capillary spaces ceases, while wa continues to pass down through the gravity spaces. In the aggreg these gravity spaces occupy but a small per cent of the space i soil, and in washing them the surface cleansed of alkali is bu small per cent of the total surface of the soil grains. If the sup of water at the surface continues, the movements downward go and only a small percentage of the alkali is washed out; contin washing only serves to carry off the alkali which diffuses out fr the fine pores into the spaces where movement is taking place.

When the supply is cut off from the surface and the gravity spa drain free of excess water, the surface tension acts upon the wa held in the capillary spaces and movement in them commences. the surface dries the upward movement continues almost entir through the capillary spaces, and as the water moves so does the alk upward to the surface.

Consideration of the above makes it plain why alkali seems to mo upward easier than downward, and why after repeated washi alkali yet remains within a soil. The example illustrates the imp tance of drainage to rapidly remove any excess of water, whi might otherwise be brought back to the surface by capillary mo ments and as it comes return the alkali to the zone of root acti The depth to which drainage should be carried depends upon t kind of soil; the object should be to lower the water to such a dep that surface tension is unable to draw the water back to the surfa

RELATION OF DRAINAGE TO ALKALI.

Drainage solves the alkali problem. The removal of alkali accomplished in two ways: (1) By withdrawing from a soil t water which has washed through the surface soil and thus removi part of the alkali. Each irrigation removes a small amount of alk and the soil continues to improve as long as irrigated. The seco

method of improvement is the prevention of the rise of alkali salts which lie below the drainage plane. In other words, the drains cut off the active upward movement and prevent the rise of the alkali.

The Bureau of Soils has been experimenting for several years upon drainage as a method of reclaiming alkali salts. The work of the Bureau has clearly demonstrated that drainage will accomplish the reclamation and permit the farming of our most sterile alkali flats.

UNDERGROUND WATERS OF SOUTHERN CALIFORNIA.

By W. C. MENDENHALL.

The greatest population and the highest cultural interests in southern California are concentrated within a wide diversified valley that extends inland 80 miles from the Pacific coast at Santa Monica, and is effectually screened from the Mohave and Colorado deserts by the San Gabriel and San Bernardino mountain ranges. These high groups protect the land on their Pacific slope from the climatic extremes of the deserts, and at the same time wring from the ocean winds the moisture with which they are laden, and which, in the form of perennial streams, makes possible the high state of cultivation that has given some of the adjacent agricultural lands values of from $500 to $2,000 per acre. Yet the rainfall is low—from 10 to 20 inches in the valleys—and this and its concentration within a few months of the year are conditions which demand irrigation to insure crops even of grain and hay, and make it imperative for the much more valuable citrus lands, walnut groves, and gardens.

EARLY IRRIGATION.

The practice of irrigation was begun early in the century by the missions, before a general settlement of the country by the Mexicans or the Americans. Short and simple ditches, which usually took their water from the perpetual springs and served a small acreage about the ranch houses, sufficed for the simple agricultural needs of this pastoral period. The construction of permanent works of a better character began before the civil war, and was most actively carried out during the seventies and eighties. The famous Riverside colony was founded in 1870, its existence depending entirely upon the successful construction of a large canal, which carried the flowing waters of the San Bernardino basin to a strip of desert mesa north of Santa Ana River. By the construction of other canals built about this period the mountain waters as they came down the canyons to the margin of the low-lying tillable lands were gradually diverted and the acreage under cultivation extended. Such flourishing colo-

nies as Anaheim, Pasadena, Pomona, Ontario, Cucamonga, Highlands, and Santa Ana owe their foundation to the diversion of these surface waters.

By 1880 the available flowing waters had been generally diverted and utilized, and the limit of the amount of land reclaimable seemed to have been reached; but the stimulus of the very high values reached by the California citrus lands, and the comparatively small acreage under cultivation as compared with that reclaimable if water were available, combined to induce a most thorough examination of all possible sources. After the appropriation of the normal stream flow, there remained two additional possibilities sufficiently inviting to enlist the attention of capital and skilled service. Because of the high gradients of the California river beds, and the steep slopes of the mountains where the greater part of the rainfall occurs, as well as because of the fact that a large part of the annual precipitation falls during heavy storms of moderate duration, there has always been a heavy loss of water through run-off during floods. If this could be saved by impounding reservoirs, a great gain would be effected. But the generally constricted character of San Bernardino and San Gabriel mountain canyons has been unfavorable to the construction of reservoirs, and actually but two important projects have been completed—the Bear Valley dam, whose stored waters have added the flourishing Redlands colony to the reclaimed areas, and the Hemet dam, less favorably situated as regards rainfall and less successful, therefore, in the matter of acreage redeemed. Another project, the Arrowhead, is under way after years of patient observation of rainfall and run-off; hence eventually there will be a further addition to the waters conserved in this way.

ARTESIAN-WELL DEVELOPMENT.

Underground water supply.—The second attractive possibility for securing additional water lay in the development of the great underground reservoirs. It had been found in the sixties and early seventies that the boring of wells in certain moist-land areas was followed by flowing water, and when the surface supplies had all been appropriated engineers turned their attention to these lands and to the storage sites as the two remaining sources which promised most in the way of increasing the available supply.

The Gage canal system, completed in 1886, has depended from the first almost entirely upon underground waters, and its 7,500 acres of splendid citrus lands are an example of what may be done with them. Since this experiment the development of underground waters in southern California has continued, until now there are nearly 3,000 artesian wells and about 1,600 pumping plants, representing a capital

of about $4,500,000 and a combined production of at least 400 to 500 second-feet continuous flow.

This development, although under way for thirty years, was given a great forward impulse by the series of dry years which began a decade ago. The previous ten years had been years of abundant rainfall, the precipitation being well above the average, although this vital fact was not generally recognized by water users. As a consequence, the acreage brought under cultivation during those years exceeded the amount which the ditches depending upon surface streams could serve when the dryer period came on. The most important and valuable of California crops are perennial plants—citrus and deciduous fruits and walnuts—which can not be rapidly adjusted to fluctuations in the water supply. A grove which does not come into profitable bearing until five years after planting represents by that time considerable capital. If the water fails it for a season, that capital is lost. Hence great energy has been displayed in the development of water as the surface supplies have dwindled under the influence of the drought. There are few important irrigating systems whose supply has not been augmented during the ten years past by the boring of wells, whose flowing or pumped water is used to make up the deficiency in stream flow. In addition much independent irrigation has been undertaken whose supply is well water entirely. A large part of this is new land, not under cultivation previous to the beginning of irrigation from wells. A smaller proportion was moist land cultivable without irrigation before the dry period and retained in the cultivated class since only by the installation of wells. The reclamation of lands in this way has been most extensive, naturally, in the artesian areas, and in those other low-lying lands bordering the artesian basins, where water could be obtained near the surface and at but slight cost by pumping, but it has been practiced in a more limited way where higher, warmer, and more valuable lands have enabled the horticulturist to lift water to greater heights and to pay the resulting higher charges.

It has been fortunate, indeed, for southern California that she has had large bodies of subterranean waters on which to draw. This fact has enabled her to come safely through so trying and generally fatal a combination of circumstances as a decade of heavy rainfall, and consequent exaggeration of her most fundamental asset, accompanying such a rapid industrial development as to constitute a boom of the first order. The reaction from such a combination is usually utter stagnation. The worst fault of our western American business character is its cheerful, careless optimism. It will believe any tale, however false, that flatters its community pride and promises fortune; it will have nothing of any fact, however absolute, that sets a limit to its resources. In the Southwest it might well parody the

well-worn motto of the court of Louis XV and say, "After us drought." But southern California has not as yet lost any exte areas of her reclaimed lands, although the deficiency of rainfa Los Angeles for the past eleven years has aggregated 26 per ce the average, and during that time and at present she has steadily increasing her acreage.

Origin of underground water.—The geologic relations which made this condition possible may be briefly outlined. The valle southern California is not a normal stream valley, carved by st action and adjusted in width, depth, and alignment to the vo and course of the stream. It owes its character entirely to agencies, those agencies being crustal movements. This divers lowland may be best described as a series of deep, irregular, cr troughs, parallel to each other and to the Pacific shore line, plun to the northwest and abutting in this direction against the gra San Gabriel Range. At the foot of this range the ridges separa the troughs are lowest, and a practically continuous valley ext from Santa Monica to San Bernardino. Farther south the separa ridges rise higher and the valley is broken by mountain chains groups. As these troughs and their separating ridges have for by geologic processes, the previously existing rivers have maintai their way across them from the higher mountains where they ris the sea, and in maintaining these courses have cut canyons in ridges and have filled the troughs with the sands, gravels, and c that are due to their erosive action. The result is a series of d bed-rock valleys filled with alluvium, across which the rivers fl These conditions give rise to certain peculiarities in the habits of rivers, peculiarities which it happens adapt them in a wonderful to man's needs as an irrigator.

Santa Ana River is the most important of these southern Cali nia streams, has the largest drainage basin, the longest course, exhibits these beneficent peculiarities in great perfection. It therefore be briefly traced as an example of the type. It rises in higher San Bernardino Mountains, where rainfall is abundant, has attained a volume of from 25 to 50 second-feet when it reac the first of the filled geologic troughs at the mouth of its upper c yon. Here it promptly sinks in the coarse débris and percol slowly below the surface, protected perfectly from evaporation contamination until it reaches the lowest point in the rim of depression. This rim forces it to the surface, and it flows acros as a living stream, the waters which escape diversion sinking ag in the gravel filling of the second trough. After a short subterran course it is forced out again by the impervious rock at Riverside N rows and continues to flow over the surface through the Santa Mountains until beyond these it reaches the inner edge of the grea

of the troughs, the Coastal Plain, in which it sinks. Below Santa Ana it rises once more in a series of strong scattered springs and escapes to the sea.

This hide-and-seek habit is characteristic of the rivers of this valley and is as ideal an adaptation to the needs of the arid-land horticulturist as though definitely planned by man for his own benefit. The lower rims of the rock folds force the water to the surface at very convenient intervals for diversion, and meanwhile not only is the water in its underground passage saved from loss by evaporation, but the irregular spasmodic supply at the canyon mouths is converted into a uniform flow which is unaffected by individual storms and responds but slowly to prolonged wet or dry periods. These basins are, therefore, not only storage reservoirs, but are most effective regulators as well, and go far to bring about that most important desideratum in irrigation practice—uniformity of supply. An additional important economic factor is introduced by the presence of artesian conditions along the lower margin of each of these storage basins.

The material with which the rock basins are filled is alluvial, river-deposited sediment. Each stream issuing from its mountain canyon carries with it the products of its erosional activity there. Debouching upon the plain, its velocity is checked and the heavier fragments are dropped. At the lower margin of any particular basin, where the velocity of flow is least, the finest materials are laid down as clay sheets. These have the original slope of the stream bed and are limited in their extent upstream. In this direction they gradually become coarser until they are no longer impervious. The waters entering the valley at the canyon mouths and percolating seaward below the surface through the more porous strata are entrapped beneath these sloping clay blankets, where under the weight of the waters behind them they accumulate pressure. Then when the impervious clay cap above them is pierced they flow.

Distribution and character of supply.—These cheap artesian waters are well distributed in southern California, and have been important elements in its development. The original area of the lands under which they were found was about 375 square miles, but it has suffered a shrinkage of 33 per cent during the last fifteen years and now measures only about 250 square miles.

Since these artesian basins are unlike the normal synclinal folds in porous rock, which have come to be regarded as the type, so they have special characteristics which bear directly upon their usefulness.

In the first place, being in wholly unconsolidated and generally coarse material, they have a high transmission capacity. So freely does the water flow through them that individual 10-inch wells have

in a few cases yielded 6 or 8 second-feet of water. Such wells do not fail because the water supplied at the head of the alluvial fan can not reach the boring, as has been the case in the Denver basin, for example. On the other hand, flowing so freely they draw down the supply at a very rapid rate, but can be restored if closed for a time, while a new supply is allowed to accumulate.

The fact that the water-bearing strata lie approximately parallel to the surface, and that the highest are very near it, facilitates development to such an extent that ranchers in many instances have found it more economical to sink a well for each 10-acre lot than to distribute from a single central well. This condition encourages the multiplication of wells and the drafts upon the artesian supply.

It is these great rock basins, with their filling of saturated alluvial wash, which constitute the important underground reservoirs that have not only tided the region over a long period of low rainfall, but have actually made possible constant additions during the dry period to the reclaimed lands. These great natural reservoirs more than compensate for the lack of sites for effective artificial storage. Their actual capacity is to be expressed in cubic miles rather than in smaller units. The San Bernardino basin has been explored by the auger for over 1,000 feet, and is roughly estimated to attain a maximum depth of 3,000 or 4,000 feet. The alluvial filling about Pomona and Chino, and that east of Pasadena, above the Paso de Bartolo, is known to extend below sea level. The great Coastal Plain basin has been explored for 1,300 feet, and its depth, were it known, would probably be found to run well up into the thousands. With a surface area of 775 square miles and on the basis of 30 per cent of voids, a very impressive but utterly valueless estimate might be made of the amount of water stored in it.

Reduction of supply.—But while the underground reservoirs have proved of incalculable value to southern California during the decade just passed, and have not only carried the country through this period, in spite of the fact that the greater part of its earlier development was carried out during and upon the basis of a decade of excessive rainfall, but have actually permitted a continual increase of acreage under irrigation, it is not to be expected that this result has been attained without affecting the water level in the reservoirs.

Water levels have, in fact, declined notably, artesian areas have shrunk, and pressures in wells still flowing have decreased markedly. The thing which causes most surprise is that these shrinkages have not been more violent. The underground supplies have been attacked in front and rear. The summer and a part of the winter flow of the mountain streams is diverted at the canyon mouths and used for irrigation, where formerly all of it sank into the gravels and

joined the underground supply. A few storage reservoirs have been built which hold a part of the winter flood waters that are now and always have been the chief source from which the ground waters are replenished. Thus not only has the supply been less during the past decade because of drought, but it has been further curtailed because of diversion and storage. In addition to this indirect attack, the great number of artesian wells and pumping plants which have been put in have directly attacked the quantity of stored waters. It is estimated that of the 225,000 acres under irrigation in the valley of southern California at present, two-thirds are dependent upon developed underground waters, of which about 400 to 500 second-feet are used, while the surface streams supply but 200 or 250 second-feet. These relations are not fixed, there being a large acreage which is irrigated with surface water when this is abundant, but with well water when the streams are low. But the irrigation from developed water alone is increasing, while that from streams is at a standstill or is shrinking, the flow of certain important streams which are due to rising ground waters having diminished during recent years. One great water company, all of whose supply of 40 second-feet except about 6 second-feet was originally artesian, now pumps at least 75 per cent of the total. The water levels in wells in important water-bearing lands tell the same story. Maximum declines of 60 or 70 feet within the past four years are of record. Declines of 25 or 30 feet are not at all rare.

Cause of fluctuations of supply.—These of course are phenomena to be expected during a period of drought. The critical point with the California irrigator who is dependent upon underground waters is to determine how much of it is due to the dry period and how much to development. Obviously this is a difficult point. The amount of water returned to the gravels each year is scarcely capable of direct estimate, at least with the data now available. The greater part is contributed of course during the winter floods, but the measurements of these are difficult, and but few attempts have been made to estimate them.

Observations upon the fluctuations of the ground-water level are perhaps of more value. A system of such observations has been begun by the Survey, but it will have to be continued for a considerable period before its results furnish a safe basis for conclusions. At present we have only two or three sets of observations within the valley which extend far enough back to be valuable. Fortunately for our thesis, their evidence is harmonious. I have selected for discussion the water-level fluctuations in a well near Anaheim, on the inner edge of the Coastal Plain. Pumping plants are numerous in this vicinity and are being rapidly increased in number, so that the phenomena

exhibited by this profile may be accepted as typical of those neighborhoods where most pumping is being done. For direct comparison with it a rainfall table has been prepared in which the departures from the average are shown for each year, since it is with the relation of each year's rainfall to the normal that we are especially concerned.

From these records it appears that from the time when the observations began in 1898 the declines were continuous and regular throughout the dry period, which was interrupted during the winter of 1900–1901 by an excess of rainfall. During this winter the water level rose 2 feet, but the gain was more than lost before the beginning of the next rainy season. The decline then continued, although irregularly, until the winter of 1902–3, another year of excess in precipitation. Here again the profile shows a rise, but again it was more than lost before the end of the year. Since that time the decline has been rapid.

The significant thing about these fluctuations is that years in which the rainfall has exceeded the average have failed to stop the decline, although they have checked its rate. With present developments then, the decline will continue, rapidly through years of deficiency, less rapidly through years of average rainfall, slowly through years of slight excess, and will cease only with an amount of excess greater than any that we have had in a decade. This is a sufficiently serious showing to call for a halt in the development of underground waters. It does not necessarily mean loss of land now reclaimed, because it is recognized that the proportion of water available for the restoration of the underground supplies increases at a rapidly accelerating rate as the rainfall itself increases—that is, where a precipitation of 15 inches may add little to the underground supplies, a fall of 20 inches may add nearly all of the last five, and a precipitation of 25 inches, well distributed throughout a long wet winter, may restore the continuous declines of half a dozen years of deficiency.

Need of moderation.—But the evidence is quite sufficient to show that it is time to stop increasing indiscriminately the number of wells for the reclamation of virgin lands. There is grave danger that the splendid subterranean reservoirs which have carried communities through the past decade without distress, and have responded so fully to every demand made upon them, may be overestimated. Such supplies are everywhere peculiarly liable to overvaluation for several reasons. Among them is the fact that if the total quantity of stored water be estimated the figures are so great that thoughtless users immediately conclude that such supplies are inexhaustible. They forget that actually it is only a very small part, often no doubt only 1 or 2 per cent of this great amount, which is, or with present methods can become, available. Again, the fact that these great bodies of

gravel are efficient regulators of the supply through rainfall, responding but slowly to periods of drought or periods of excessive precipitation, and showing but slowly the effects of overuse, leads many to suppose them wholly independent of these controlling factors, and so encourages them in their campaign of overdevelopment. As a matter of fact, close, careful, and continual observations should be made of fluctuations in ground-water levels as development proceeds, and these, when compared with rainfall measurements, will give a safe, scientific basis for the regulation of the acreage irrigated from ground waters.

Meanwhile, development must proceed with extreme caution, for obviously nothing worse can happen to a community than to be forced to abandon lands which have been reclaimed at a great expenditure of time and capital.

COST OF STREAM-GAGING WORK.

By E. C. Murphy.

The cost of obtaining the data on which the monthly and annual estimate of flow of a stream are based is made up of four items, namely, cost of equipment of station, cost of gage records, cost of each gaging, and number of gagings a year.

The cost of equipping a bridge station will generally be from $10 to $25; the cost of equipping a cable station will generally be from $25 to $500, depending on the length of span of the cable and the accessibility of the location.

The gage readers are generally paid from $3 to $5 per month for from eight to twelve months per year. In some States, as, for example, Maryland, the gage readers are paid by the State. The records of a number of stations, especially in the South, are obtained from the Weather Bureau free of charge. In some States, notably New York, gage records are furnished by private parties free of charge. Some of the railways cooperate in stream-gaging work by furnishing the resident hydrographer with free transportation to his station.

The cost of a gaging depends mainly on the time required to reach the station and the cost of transportation. In some sections of the country, notably New Jersey, two or three stations per day can be visited; in other sections, as Wyoming and Oregon, two or three days' travel are necessary to reach a single one.

The number of gagings that are necessary per year after a station is once rated depends on the character of the bed of the stream, not only at the station, but also for a considerable distance above and below it. Two or three measurements a year are sufficient at some of the New England stations, whereas from four to twelve measure-

ments a month are necessary on some of the streams of changeable bed in the West. The following table shows the estimated cost of stream-gaging work at some of the gaging stations in 1903:

Estimated cost of stream-gaging work in 1903.

[Prepared from reports on Form 9-237.]

District or State.	Hydrographer.	Number stations included in estimate.	Number of visits.		Cost per visit.			Total yearly cost.		
			From—	To—	From—	To—	Mean.	From—	To—	Mean.
New England	N. C. Grover	23	2	6	$7.00	$31.00	$13.88	$34.00	$169.80	$116.57
New York[a]	R. E. Horton	[b]27	1	4	4.00	25.00	12.40	15.00	150.00	63.37
Do.[a]	do	26	3	16	4.00	15.00	8.20	50.00	150.00	144.00
Michigan[c]	do	[b]5	1	2	10.00	30.00	24.00	30.00	75.00	51.00
Do.[c]	do	11	1	6	10.00	20.00	11.90	25.00	175.00	94.10
Pennsylvania, Maryland, Virginia, and West Virginia.	E. G. Paul	16	....	6	11.00	16.00	12.88	66.00	132.00	[d]100.00
North Carolina, South Carolina, Virginia, and West Virginia.	E. M. Myers	23	4	10	7.50	18.00	10.95	79.00	174.00	116.74
North Carolina, South Carolina, Tennessee, Georgia, Alabama, and Mississippi.	M. R. Hall	[e]34	4	10	7.50	17.75	10.79	68.00	136.50	97.90
Washington	Geo. H. Bliss	10	4	6	15.00	45.00	28.38	125.00	275.00	.....
South Dakota	R. F. Walter	9	4	5	5.50	30.00	11.33	45.00	185.25	79.13
Chicago	E. Johnson, jr.	26	9	12	5.35	22.50	17.69	107.00	330.00	243.51

[a] The gage records for 21 of these stations are furnished free.
[b] Stations at weirs and dams.
[c] The gage records for 11 of these stations are furnished free.
[d] No allowance for office work.
[e] The records of 29 of these stations are furnished free of charge, and the cost of gage records of the other stations at from $1.50 to $3 per month.

This table shows in a general way the cost per gaging and the total cost of a gaging station per year in different parts of the country. The total cost depends on so many items that differ so widely in different sections of the country that it is very difficult to make a just comparison.

The mean cost per visit to a current-meter gaging station in the districts east of the Mississippi varies from $12 to $17.75, the latter being for the Chicago district, where the stations are widely scattered, and the former in New York State, where the stations are not far distant from headquarters.

The yearly cost per visit is less for stations at dams and weirs than for current-meter gaging stations. This difference is partly due to the fact that the gage records at most of the former are furnished free of charge.

The following table, prepared from the annual reports of M. C.

Hinderlider, gives the actual cost of stream-gaging work in the Denver, Colo., district for 1904 and a part of 1903:

Cost of stream-gaging work[a] in the Denver, Colo., district, 1903.

[Prepared from reports of M. C. Hinderlider, engineer.]

State.	1903.							1904.					
	Gaging regular stations.				Miscellaneous.		Average cost of all gagings.	Regular gaging stations.			Miscellaneous.		Average cost of all gagings.
	Number of stations.	Gagings per station.	Number of gagings.	Average cost of gaging.	Number of gagings.	Average cost of gaging.		Number of stations.	Number of gagings.	Average cost of gaging.	Number of gagings.	Average cost of gaging.	
Colorado	45	3 to 22	456	$6.84	401	$1.20	$2.89	58	419	$7.63	72	$7.82	$7.68
Wyoming[b]	16	1	20	64	6.86	3	1.13	6.61	12	109	13.68	9	5.92	13.07
Nebraska[b]	16	1	11	13	6.30	13	3.34	5.80	10	69	7.33	30	2.17	5.76
Kansas[b]	12	1	4	21	9.39	4	12.65	9.94	11	75	10.75	5	10.82	10.76
South Dakota									13	90	11.09	49	1.20	7.60
New Mexico									16	78	7.93	2	7.03	7.90
Oklahoma and Indian Territory									8	17	12.69			

[a] Not including gage readings. [b] For the period July 1 to December 31, 1903.

The cost per gaging at regular gaging stations in 1903 varied from $6.30 to $9.39 and in 1904 from $7.33 to $12.69.

The average cost per gaging in Wyoming in 1903 is about one-half that in 1904, on account of the work being done in 1903 by local men. The results obtained by these local men were not found satisfactory, and the work was done in 1904 by the resident hydrographer.

The cost of miscellaneous gagings is generally much less than of those made at regular gaging stations.

The actual cost of carrying on the stream-gaging work at 15 gaging stations in Idaho for the year 1904 was $2,422.97; the cost per station varied from $83 to about $255, the mean being $161.53. The amount spent on the equipment of 11 of these stations during this year varied from $14 to $92, the mean being $39.86. The number of visits made during the year varied from 2 to 9, and the cost per visit varied from $2 to $25, the mean being $6.80.

The actual cost of stream-gaging work at 34 gaging stations in New York State from July 1 to December 31, 1904, was $2,114.69, the cost ranging from $13 to $110, the mean being $66.08. The number of visits made during these six months varied from 1 to 6. The cost per visit varied from $3.50 to $29, the mean being $13.16, the larger of these values being for visits when repairs were made to the station. The cost of some of these New York stations includes the cost of computing two years' records.

EQUIPMENT OF A CABLE GAGING STATION.

By E. C. Murphy.

The equipment of a cable gaging station consists essentially o cable with its turn-buckle for increasing or decreasing the sag, supports for keeping the cable at the proper height, the anchor for holding the ends of the cable in place, the car or box from w the measurements are made, the tag line and its tags marking tances across the stream from an initial point, and the stay for keeping the meter in place in the water when the flow is rapid

The cost of erection of a cable is generally so large, compared the cost of any part of the equipment, that it is wise to make parts abundantly strong and durable. Failure of the cable quently results from drift (parts of floating trees) catching o during flood, and hence the supports must be long enough to the cable above any drift that may come down the river, and als permit the highest floods to be measured from the car.

Galvanized steel wire cable is preferable to ungalvanized cabl account of its greater durability. The sizes of the galvanized c given below will be found safe for different spans or lengths betw cable supports:

Proper diameter and sag of galvanized steel cable, with live load of 450 pou for spans of 100 to 800 feet.

Span.	Diameter in inches.	Sag in feet.	Str
100 feet	$\frac{1}{2}$	4	2
200 feet	$\frac{9}{16}$	6	4
300 feet	$\frac{5}{8}$	8	5
400 feet	$\frac{3}{4}$	10	6
500 feet	$\frac{3}{4}$	12	7
600 feet	$\frac{7}{8}$	12	10
700 feet	1	14	12
800 feet	$1\frac{1}{8}$	15	16

The diameter is computed for a live load of 450 pounds (car two men) on the cable, at center of the span, and an initial t sion due to the sag (given in the table), using a factor of safety about 5. The sag given in the table is the least allowable. If i increased, the factor of safety is increased. The cable should not bent in making connections to a shorter radius than 2 inches; and turn-buckle and connections should have a safe working strength an amount given in the last column of the table.

It occasionally happens that a tree can be found on one or b

sides of the stream at the place selected for the station that can be used to support the cable. If such trees can not be found, then for spans less than 300 feet a single post, such as a telephone or telegraph pole, or sawed timber 10 or 12 inches on a side, can be used, with the lower end firmly set in the ground and notches cut in the upstream side for sustaining the cable. Two pieces of 6 by 8 inch timber crossed and bolted together near the upper end, called "shear legs," can be used instead of a single post, if desired. High supports for long spans are made of two inclined heavy timbers connected by horizontal timbers with diagonal bracing.

The form and size of anchorage depends on the length of span and the material of the bank. For spans of less than 200 feet and earth bank a log or sawed timber 12 inches in diameter and 5 or 6 feet long buried at least 4 feet in the ground will answer. For longer spans it is necessary to place cross timbers on top of the timber to which the cable is attached and to bury them more deeply in the earth than for the shorter spans. Old iron rails can be used to advantage instead of timber in the anchorage, and rock in place of earth on top of the timbers is desirable.

The end of the cable is wrapped a couple of times around the deadman and fastened to the cable with clips. A block and tackle and a team of horses are necessary in the erection of long cables.

If there is solid rock on one or both banks that can be used for an anchorage, a hole 12 to 18 inches in depth and of one-eighth inch larger diameter than the cable can be drilled into it. A bolt slightly less in diameter than the hole, having a loop in the upper end and a slit and wedge in the lower end, can be leaded into it. The end of the cable is fastened with Crosby clips to this loop on the end of the bolt. A right-and-left turn-buckle of sufficient length to take up the sag of the cable should be placed between the anchorage and the support on one side of the stream.

The car from which the measurements are made should be about 4 feet long, 3 feet wide, and 1 foot deep. Each end is fastened to a pulley on the cable, either by galvanized steel wire cable or by a 2 by 4 inch timber at a height such that the car can easily be pulled along by a man in it. The pulley should be at least 8 inches in diameter and made so that it can be easily taken off the cable.

Barbed wire can be used as a tag line. It is not likely to be stolen, and the tags can easily be fastened to it and replaced if they drop off. The ends of the line are fastened to the cable supports.

A single heavy galvanized wire or a three-eighths inch or one-fourth inch galvanized steel wire cable can be used as a stay line. A pulley with a swivel on it is placed on this line, to which a sash cord is attached during the measurement of the flow of the river. This

stay line must be placed at a sufficient distance upstream so th will exert only a small upward pull on the meter. If the stay is too near the cable, it will not permit the lowering of the mete the bottom of the stream directly underneath the cable.

SILTING OF RESERVOIRS.

By W. M. Reed.

The matter of silt deposit in storage reservoirs is one that wil encountered in many of the projects to be undertaken by the Re mation Service.

Those who have had to deal with the silt-laden streams of West have long known that the silt question is an important But little of a definite nature has been written upon this subj the question having been dodged in the hope, perhaps, that by s mysterious process the silt would not become the trouble tha often predicted and toward which all indications point.

The writer has had opportunity to study this question somew during the present year, and the results have been quite satisfact from an educational standpoint, even if they do not offer a solut of the problem.

Pecos River is a typical southwestern stream, always carry some silt in suspension, and at flood time carrying large quantit it does not, however, carry any such amount as does the Rio Gra A comparison of the sediment in the two streams was made by P Arthur Goss, of the New Mexico Agricultural Experiment Stati and the results published in Bulletin No. 34 of that station, wh gives the sediment in the Pecos as 180 parts of suspended ma to 100,000 parts of water, and in the Rio Grande as 831 to 100,00

During the winter of 1903–4 a board of consulting engineers the Reclamation Service visited Lake McMillan, the principal stor reservoir of the Pecos Irrigation Company, and instructions w issued that should this reservoir become empty a survey should made to determine the amount of sediment that had been deposi during the ten years that the reservoir had been in operation.

The drought of 1903 continued into the summer of 1904, and June 1, 1904, the reservoir was empty of all stored waters. A s vey was at once begun and the work was pushed almost to completi when on June 17 a rise in the river brought to an end all operati along this line; not, however, before nearly all the data sought h been obtained.

This reservoir had been in operation for ten years, and theref the sediment found represents the amount deposited in that peri The reservoir had never been accurately surveyed and it was nec

sary to determine its capacity before the silting commenced as well as its capacity at the time of this examination.

The original capacity was found to have been 28,732 acre-feet and its capacity June 1, 1904, was 16,500 acre-feet. This shows a loss of storage capacity in ten years of about 42 per cent, or a little more than an average of 4 per cent per annum.

It had been contemplated originally to construct a reservoir of much greater capacity, but, owing to some trouble from floods in the early existence of the reservoir, the western spillway was cut down several feet below the spilling point and was not reconstructed until during the past winter, when, at a very small expense, the capacity was increased to about 46,000 acre-feet.

One cause of the rapid silting up of this reservoir can readily be understood. The flow of the river probably averages ten times the capacity of the reservoir, and as nearly all the silt is taken out of the water at this reservoir the process of silting up is very rapid. Had the storage capacity been equal to the entire flow of the river the per cent of silt would have been small. This indicates that small reservoirs on streams of great flow have a very low ultimate efficiency.

One of the points not satisfactorily determined by the investigations was the amount of silt deposited outside of the storage area of the reservoir. The amount is known to be large, the depth of silt increasing rapidly as the intake end of the lake is approached, and a few hurried borings outside the real storage area showed a greater depth of sediment than at any point within that area. It is a positive fact that a large proportion of the entire silt deposit is outside the storage area, but exact information could not be obtained on account of the high water.

It seems that when the reservoir is full, or nearly so, and a flood comes down the river, meeting with the level surface, the silt begins to drop and for several miles above the reservoir the banks overflow and the topography is entirely changed. This would indicate that where small reservoirs are constructed on streams of great flow and little fall a large part of the silt will be deposited outside the reservoir.

A more detailed report of this investigation has been submitted to the chief engineer and published in the Third Annual Report of the Reclamation Service. One of the most important of the conclusions reached as a result of the investigation is that in silt-laden streams, when the valley of the river must be used for the storage of the floods, thereby accumulating all the suspended matter, reservoirs of capacity as nearly as possible equal to the entire flow of the river will be the most economical.

The writer has not put much faith in the theory that any consid-

erable part of a large silt deposit in a reservoir can be removed by ordinary flushing. The current through a reservoir is not sufficiently strong to pick up much of the silt, and in cases that have come under personal observation the sluice gates have operated only to cut out a small narrow channel, not materially increasing the storage capacity.

It is possible that when the value of water becomes much greater, as perhaps it may at no very distant time, mechanical appliances may be used to aid the current to take a large proportion of the silt again into suspension and remove it through the sluiceways that are almost invariably placed in reservoirs; but considering the present value of water, mechanical methods of removing silt seem to be without the bounds of economy, except in rare cases.

FARM-UNIT CLASSIFICATION.

By D. W. Ross.

PROPOSED PLANS FOR CLASSIFICATION.

A circular letter on farm-unit classification issued by the chief engineer under date of October 29, 1904, invites discussion by the engineers of the service of the subject of farm-unit classification, particularly in relation to apportioning the cost of reclamation over the lands to be reclaimed, keeping in mind the character of each farm unit.

The letter referred to submits three plans for settling this difficulty which are thought to be worthy of consideration, and invites comment on the same. The following are the alternative plans suggested:

(1) That the classification sheets should contain in each area the equivalent acreage of first-class irrigable land, distinguished from the total acreage by being placed within a circle. The charge will be uniform per acre of first-class land or its equivalent.

(2) Assuming that the standard area is 80 acres, the charge should be made for that acreage, regardless of the actual area of the farm unit. In case a smaller subdivision has been made under the project near the towns the charge to be for the actual area in each farm unit, on the theory that in such cases both the land and the crops would have a value as great as the land and the crops of the larger area farther from the towns.

(3) That the charge per acre should be made proportional to the quality and value of land. For example, if a 40-acre tract, specified as first-class land on account of quality or location, is charged at $25 per acre, another tract of second quality containing 80 acres would be charged at $12 or $15 per acre, etc.

Commenting on these plans, the letter states that No. 1 would probably call out the least objection from the settler; No. 2 would be simpler to manage and involve the least danger of error, and No. 3 would give opportunity for criticism on the part of the larger portion of the settlers.

Plan No. 1.—Where the tract to be reclaimed is public land and is open to entry while the construction of the works is in progress, full consideration will likely be given all matters relating to the quality and location of lands open to entry by the intending entrymen; that is, in entering a given tract each entryman will first consider its location and quality, and knowing the price per acre which he will be called upon to pay for his water right, he will naturally decide whether or not the land is worth entering at that price. Those who are fortunate enough to make the first filings will, of course, select the best land, and each succeeding entryman will select the best land remaining, until the poorest land of the tract remains to be entered, when the same question arises as before—is the land worth what it costs to reclaim it? If it is, it will be entered; if not, it will remain vacant, but probably for only a short time. So it is my opinion that but very little attention need be paid by the Reclamation Service to the relative value of farm units where entrymen are at liberty to exercise their own judgment in selecting their claims. I do not believe that the first plan proposed is necessary.

Plan No. 2.—Regarding plan No. 2, considerable importance seems to be attached to the location of the tract. If it is close to a town, it is proposed to charge a greater amount for the water right, so as to place it on an equality with perhaps a larger tract situated farther from a center of population. The principal objection which I see to this plan is that where a large area of public land is to be reclaimed there is nothing settled regarding centers of population; such matters are to a very large extent in the future, so that if an attempt should be made to place the entryman who is remote from a townsite on an equality with one whose land may join a townsite the result may be entirely upset in a few years' time through the development of towns in unexpected localities. For this reason I do not believe the plan proposed is a sound one.

Plan No. 3.—Plan 3 proposes to make the charge per acre proportional to the quality and value of the land. This involves the same principles that it is sought to apply to plans 1 and 2.

ALTERNATE PLAN FOR ASSESSING COST.

It would appear that the principle adopted in fixing the price of a water right should be one which will have general application not

only to public lands, but to private lands as well. If the ques could be approached on the theory that what is paid for by irrigator is a proportional interest in the works the problem w be comparatively easy of solution. What the settler pays fo called a "water right," acquired by him by virtue of stock hel an association. It means primarily a proportional interest in works constructed, and under the provisions of the reclamation a seems to be contemplated that the settlers shall, at some future t be given control of the works constructed; so that whatever paym may have been made for so-called "water rights" would, as a ma of fact, represent certain equities in the works themselves. Wl these water rights or equities are purchased through a water us association it is proposed that each water right purchased shall represented by a share of stock issued by the association. T places water users' associations in practically the same class as c munity irrigation companies, which are so common all over the W On this basis, then, one share of stock would be worth as much another. The land, of course, will not be all of the same quality, the shares will likely cost the same.

While it is a fact that desert land owes its first real value to construction of irrigation works, and every acre of land is, or sho be, worth what it costs to reclaim it, the productive value of the la or its value after it is improved, very soon exceeds this first outl which is finally lost sight of entirely, and the poorest land upon wh water is applied is usually worth a great deal more than the aver cost of reclamation.

The quality and lay of the land, however, is an important fac in determining the amount of water necessary for irrigation, wh in turn frequently determines the amount of the annual charge tax, which runs perpetually. But the amount of water needed is necessarily proportional to the first cost. Land which appears to of the very best quality and which, according to the principle out in the circular letter, would pay the highest price for a wa right, might require a comparatively small amount of water, and the cost of service is based on the quantity of water delivered, t charges running against this land perpetually might be very lo But lands which are inferior in quality, and which as a result wou pay a smaller charge to begin with, might in the end pay an exce ingly high annual maintenance tax, owing to the great amount water required for irrigation. Or these two cases might be entire reversed; that is, the superior land require an exceedingly lar amount of water, while the inferior might require but very litt In this case it might with reason be held that the owner of the inferi land should pay a larger proportion of the first cost of reclamation.

It is my opinion, therefore, that if we hold that the irrigator

purchasing a proportional interest in the works for which the money is expended no one will be done an injustice when the charge is made uniform over all the land, unless extraordinary expense has been incurred in carrying water to a certain tract, in which case the entire tract involved might with justice be made to pay a greater price per acre.

I am of the opinion that the distribution of the cost of an irrigation system should be allotted to certain natural subdivisions of the territory involved rather than to separate farm units, since greater expense may be incurred in reaching one natural subdivision than another, but all the lands in each subdivision should be assessed the same—that is, the shares of stock or water rights should cost the same.

The benefits to be derived from the use of water can not, in my opinion, be very accurately estimated. The cost, however, of conducting water onto certain lands can be definitely determined, and it seems to me that this should be the basis for equitably proportioning the amount expended in the construction of works.

COST OF POWER FOR PUMPING IRRIGATING WATER.

By H. A. Storrs.

Many factors must be considered in determining the feasibility of pumping water in large quantities for irrigation uses, and no factor is more important and more variable than the cost of power and of operating the pumping plant.

ELECTRICALLY TRANSMITTED WATER POWER.

In many sections of the arid West water power may be developed and the power transmitted electrically from the mountains, where the power plants are usually located, to the valley lands, where the water is to be pumped and used. The commercial cost of electric power so obtained may be as low as 1 cent per horsepower hour delivered to the pump motor. On this basis the cost of power for pumping water to any required height would be about 2¼ cents per acre-foot for each foot of height to which the water had to be lifted. And if, for instance, each acre of land to be irrigated required a total depth of 3 feet of water during the irrigation season and the water had to be pumped a total height of 50 feet, the total annual cost per acre for the power required for operating the pumps would be about $3.40.

Commercial electric-power companies usually find it necessary to charge more than 1 cent per horsepower hour—frequently 5 cents or more. These higher rates are not, however, prohibitive where the lift is not great or a small auxiliary supply is required whenever

the main supply proves inadequate or the value of the crops is tively high.

On the other hand, the actual cost of supplying power to motors will often be less than 1 cent per horsepower hour, dep ing on the first cost of the hydraulic works—such as the dam, fl canal or pressure pipes, etc.—the size of the power plant, the leng the electric transmission line, etc.

In the case of national irrigation works, minimum costs ma expected for electric power developed and used for pumping poses, since no interest is charged by the Government on the m advanced for installing the plant, and the item of profits involv commercial enterprises is here eliminated, the users of the p being themselves the owners of the power plant.

Still another reason for expecting a low cost for electric p for pumping irrigation water should be noted in the case of bined gravity and pumping systems. Here it often happens one dam serves the double purpose of securing storage or diver for the gravity supply and water power for generating the ele power required for pumping.

Again, a power plant may sometimes be placed in the main c of a gravity system where the nature of the country requires water to descend suddenly to a lower level, making the additi cost for the power development little more than the bare cos buildings, water wheels, and generators. In such cases it be possible to deliver electric power to motor-driven pumps at than one-half cent per horsepower hour.

STEAM POWER.

But many sections of the West where water for irrigation mus pumped are not so fortunate as to possess water-power possibili It then becomes necessary to hunt for a cheap fuel supply.

Coal.—Coal and oil are found in many parts of the arid regions may often be delivered at the pumping plants at very low Western coals are, however, as a rule, poorer steam producers t coals from the Eastern or Middle States. Tests to determine rela evaporative power have been made at the coal-testing plant of United States Geological Survey at the Louisiana Purchase Ex sition at St. Louis, which when worked out will afford reliable data comparing the steam-producing qualities of varieties of coals f all parts of the United States. These tests will be of special valu regards western coals, which differ greatly in their characteris and about which much less has been learned by practical use tha known regarding the coals of the East, which have been longer in

The results of various commercial tests indicate that under sim

conditions 1 pound of the bituminous coals of Pennsylvania or West Virginia will evaporate about 10 pounds of water into steam; 1 pound of Illinois or Missouri coal will evaporate about 7 pounds of water into steam, and 1 pound of western lignite will evaporate about 5 pounds of water into steam.

Many grades of coal besides the lignites are, however, found in different sections of the West, Colorado alone producing coals ranging all the way from lignite to anthracite. On account of these extreme variations in the character of western coals, the cost per horsepower for the fuel required in steam-pumping plants will vary widely in the different sections of the arid regions.

Hence, in order to estimate closely the probable annual cost of coal for a given pumping plant, it is as important to know the steam-producing power of the coal to be used as to know its cost per ton.

In designing steam-pumping plants care should be exercised in selecting the boiler and in designing the boiler setting to adapt these to the peculiarities of the kind of coal to be used. A plant that would give excellent results with anthracite or bituminous might be very inefficient in burning lignite.

Engines.—Having determined how many pounds of steam may be expected with the kind of coal to be used it becomes necessary to determine how many pounds of steam will be required by the engine to produce a horsepower hour. This will depend upon the size and type of engine used, as shown by the fact that while a 500-horsepower simple, high-speed, noncondensing engine may require 32 pounds of steam per horsepower hour, and a compound, slow-speed, noncondensing engine about 25 pounds, a compound, high-speed, condensing engine of the same size will require only about 20 pounds of steam per horsepower hour, and triple-expansion engines, steam turbines, and large, slow-speed, direct-connected steam pumping engines may require less than 12 pounds of steam per horsepower hour.

In view of all these variable factors it is evident that pumping plants of various designs and sizes, using varieties of coals which differ widely in their steam-producing values, will show great differences in the annual cost for fuel.

Sometimes it may happen that a large and efficient plant will burn bituminous coal and be able to produce one-half of a horsepower per hour per pound of coal consumed, whereas a smaller plant using boilers and engines of cheaper and less efficient design and burning lignite may be able to produce not over one-eighth of a horsepower per hour per pound of coal consumed.

The above are not extreme cases, but merely serve to show that some plants may use four times as many tons of coal as others in doing the same amount of work.

EFFICIENCY OF PUMPS.

Pumps.—Moreover, the efficiency of the pumps would naturall lower in the smaller than in the larger plant, and losses by fri and leakage in the suction and pressure pipes may further vary ratio of coal used in the several plants. For comparison, take a p using coal which costs $3 per ton and requiring 5 pounds of burned under the boilers for each horsepower delivered to the pu per hour. Assuming an efficiency for pumps, suction and disch pipes of 60 per cent, the fuel cost per acre-foot per foot of lift w be about 2 cents. To this must be added the cost of labor for ope ing the plant and depreciation and repairs to machinery, which w bring the cost to 3 cents per acre-foot per foot of lift, or a total co $4.50 per acre per year, based on a duty of 3 acre-feet per acre year and a lift of 50 feet. In general, the larger the pump units the higher the lift the smaller will be the cost per acre-foot per of lift.

As a practical illustration of what is now being done, consider pumping plants in use for supplying water for irrigating sugar-c plantations in Hawaii. Ninety-five per cent of the pumps are ste driven, direct-connected, reciprocating pumps of Worthington Riedler type. The lifts are usually from 100 to 500 feet. Th steam plants contain the most efficient equipment obtainable. price of coal averages about $12 per ton.

The cost of pumping irrigating water under these condition reported by Mr. Jared G. Smith, special agent of the agricultu department in Hawaii, as follows: The cost for coal for two ste driven, direct-acting, plunger pumps, with a combined capacity about 22 acre-feet per day, pumping against heads of 95 and 100 f respectively, averaged about 4.2 cents per acre-foot per foot of li the cost for coal for three Riedler pumps, having a combi capacity of about 66 acre-feet per day, pumping against heads of and 300 feet, averaged a trifle over 1½ cents per acre-foot per foot lift.

This is an excellent showing for the Riedler pumps, consideri the high price of coal. The cost per acre per year, assuming a d of 3 acre-feet per acre and a pumping lift of 200 feet, would about $9. This, and much greater annual costs, can easily be p from the yearly receipts from an acre of sugar cane, since the aver yield is about 11 tons of sugar per acre and its selling price per ton.

In general, the higher the lift the less the cost per acre-foot per f of lift. For comparison, consider the costs for two large pumpi plants in Egypt, where the pumping lift was only 6½ feet. The c of coal being $9 per ton, the cost per acre-foot per foot of lift was

one case 7.2 cents and in the other 8.5 cents, including fuel and labor. Compound condensing engines were used, and presumably the whole plant was designed for high efficiency.

Oil.—Crude oil burned under steam boilers is an ideal fuel when its cost is not too high. Oils from the wells of the principal oil fields of the country vary little in their steam-producing qualities as compared with the variations in different coals.

Oil usually gives better efficiency than coal under steam boilers, as shown by tests made by the Engineers' Club, of Philadelphia, giving the following results: 1 pound anthracite coal evaporated 9.7 pounds of water; 1 pound bituminous, 10.14 pounds; 1 pound fuel oil (36° gravity), 16.48 pounds water, indicating that a pound of oil will evaporate 60 per cent more water than will a pound of coal. Tests made in 1893 by the Twin City Rapid Transit Company, of Minneapolis and St. Paul, showed that in their plant it was equally economical to burn Lima oil, costing 95 cents per barrel, as to burn coal costing $3.85 per ton, the evaporation of the coal being 7½ pounds water per pound of coal; these results include the difference in the cost of handling the coal, ashes, and oil. A test made by the Illinois Steel Works showed that one week's work required 2,731 barrels of oil against 848 tons of coal to do the same work, a ratio of 3.22 barrels of oil to 1 ton of coal, or about 2½ pounds of coal to 1 pound of oil; Indiana block coal was used. In this case the cost for oil, at 93 cents per barrel, would equal the cost of coal at $3 per ton to do the same work. On the basis of 2 pounds of oil burned under the boiler for each horsepower hour delivered to the pump shaft, the cost for oil would be about 2 cents per acre-foot per foot of lift with oil at 95 cents per barrel, or a total cost of about $4.50 per acre per year, assuming a duty of 3 acre-feet per acre and lift of 50 feet.

INTERNAL-COMBUSTION ENGINES.

Oil may be used with greater efficiency, however, in internal-combustion engines, and these cost less than a steam boiler and engine of the same capacity, besides requiring less labor to operate.

These engines, if designed to burn crude oil, are provided with an attachment called a generator, in which the heat of the exhaust from the engine is applied to the oil, thus raising its temperature sufficiently to separate the volatile matter from the residue. The gas thus formed is burned in the engine cylinder with a high thermal efficiency. The residue, which may amount to 50 per cent of the crude oil used, is suitable for many purposes, such as lubrication, road surfacing, etc.

The thermal efficiency of steam plants ranges from about 5 per cent to 10 per cent; that is, only 5 per cent to 10 per cent of the heat

energy in the coal or oil burned is transformed into useful work, remaining 90 per cent or 95 per cent being lost in the boiler engine. The thermal efficiency of internal-combustion engine not often less than 20 per cent, and is frequently more than 30 cent. A recent test of a 240-horsepower Diesel oil engine show thermal efficiency of 42.8 per cent.

To illustrate, assume that an oil engine, using crude oil of wl the calorific value is 18,000 heat units per pound, producing a r due amounting to one-half of the quantity of oil used, show thermal efficiency of 25 per cent. Then about 1.2 pounds of cr oil would be required per horsepower hour, costing about 0.4 c if oil costs 90 cents per barrel. The cost of oil would then be ne 1 cent per acre-foot per foot of lift, if, as before, pump efficiency taken at 60 per cent. Adding one-half cent per acre-foot to co labor, repairs, and depreciation, the total cost per year, assumin duty of 3 acre-feet per acre and a pumping lift of 50 feet, woul about $2.25 per acre.

The small gas or oil engines used for pumping usually burn tillate, gasoline, or kerosene, and require about half the quantity t would be required if crude oil were used to do the same work. cost per gallon varies from about 10 to 20 cents in different secti but at 15 cents per gallon the cost per acre-foot per foot of lift wo be about 3½ cents. If, as before, we add one-half cent for labor, making 4 cents per acre-foot per foot of lift, the total cost, based o duty of 3 acre-feet per acre and a 50-foot pumping lift, is appro mately $6 per acre per year.

Some of the results actually obtained in portions of California reported as follows: Five engines, rated at 5, 6, 12, 16, and 20 ho power, all burning distillate which cost 10 cents per gallon, c respectively, 4.3 cents, 7.6 cents, 2 cents, 1.1 cents, and 1.9 cents acre-foot per foot of lift for fuel and operation. Two engines ra at 20 and 22 horsepower, burning crude oil which cost 3½ cents gallon, cost, respectively, 0.9 cent and 0.8 cent per acre-foot per f of lift for fuel and operation.

In general, large engines are more economical than small, and statement of costs given above seems to bear this out, with so exceptions. Two items enter into statements of this kind which not always clearly defined and so affect comparative results un countably. One indefinite item is, how much is charged to the pl to cover operating expenses, in some cases practically nothing be charged, it being claimed that the man who ran the pumping ou had to be employed anyway and the amount of time given to t work did not appreciably lessen the amount of other work he able to perform. The other uncertain element is the efficiency of

pump as affected by the relation between the speed of the pump and the pumping lift. It is often inconvenient to change pulleys so as to keep the speed of the pump right for the varying lifts sometimes encountered; consequently the plants are operated sometimes for long periods at comparatively low efficiency.

GAS ENGINES.

All internal-combustion engines really operate as gas engines, since even when crude oil, distillate, gasoline, or kerosene are burned in the engine this liquid fuel is transformed into a gas prior to combustion either before or after entering the engine cylinder. It is therefore but a step from oil engines, so called, to gas engines proper. This distinction simply implies that the latter type of engine receives the gas consumed by it from an independent source, namely, some kind of gas producer.

Natural gas.—On irrigation works it will not often happen that natural gas or illuminating gas can be supplied to gas engines for operating pumps, but the possibilities of producing in an economical way some kind of fuel gas for pump engines are worth considering.

Producer gas.—The fuel gas known as "producer gas" is probably best suited to the conditions met in irrigation problems. The design of the producer-gas plant will depend upon the character of the fuel available. The best results may be expected when anthracite or coke are used, yet excellent gas can be produced with good economy from lignites or very poor grades of bituminous coals. Anthracite coal yields in producer-gas plants of 100 to 400 horsepower capacity about 75 to 80 cubic feet of gas per pound of coal consumed, and the calorific value of the gas is about 125 to 140 heat units per cubic foot. A gas engine having a thermal efficiency of 25 per cent and a mechanical efficiency of 85 per cent, if supplied with this gas, would consume 90 to 100 cubic feet of gas per horsepower hour. This corresponds to 1.1 to 1.3 pounds of coal per horsepower hour. Either with lignite or other grades of coal having only two-thirds the heating value of anthracite, a combined plant of this kind would require less than 2 pounds of coal per horsepower hour, which is less than half the amount required for steam plants of similar size.

Makers of gas engines and producer plants will guarantee that the coal consumption will not exceed 1¼ pounds per brake horsepower hour for sizes above 100 horsepower, and undoubtedly better results than this have been frequently obtained commercially. On this basis, with coal at $5 per ton, assuming as heretofore a net efficiency of 60 per cent for pumps, suction and discharge pipes, the cost per acre-foot per foot of lift is about 0.7 cent. The same results would be

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secured by using a poorer coal, like lignite, costing $3.20 per t about 2 pounds were required per horsepower hour. In either the cost for the coal required for pumping would be about $1.0 acre, on the basis of 3 acre-feet per acre and a lift of 50 feet.

Where pumps take their water from wells, smaller engines 100 horsepower are usually required, and a single gas-producer will have to supply several small pumping plants, which may b siderably scattered. It thus becomes necessary to extend gas from the gas producer to the pumps, thus increasing the first c the pumping system somewhat. This additional first cost however, be more than offset by the saving in fuel and oper expenses. By this plan a considerable number of pumps, locat wells scattered over several square miles, might be more econom operated by gas engines supplied from a central gas plant th any other way.

The first cost of gas engines and producer plants would be what more than that of the usual steam engines and boilers o same rated horsepower, and the depreciation and repairs would haps be slightly greater. On the other hand, the cost of fuel labor for operation might be reduced 50 per cent or more.

Wherever large pumping plants are required, as for lifting from a canal, reservoir, or stream to land too high to be reache gravity systems, a combination of gas engines and a fuel gas would probably effect a very great saving over steam equipme oil engines as regards fuel, besides being quite as reliable, safer, requiring less skilled labor in their operation.

SUMMARY.

As a résumé of the above outline of the principal sources of p available for pumping purposes and the relative costs involved following statement seems warranted:

That the cheapest power in those localities where the condi for developing and transmitting the power are favorable, wil derived from water-power plants; that steam boilers and eng should be selected only for large plants and in localities where whether coal or crude oil, is exceptionally cheap; that for s plants internal-combustion engines should generally be used, w ever crude oil, distillate, gasoline, or kerosene can be obtaine reasonable prices, and that the greatest economy may be expe where crude oil is used; that in the majority of cases, where fu some kind must be the source of power, the combination of engines with fuel gas-producing plants should give the most s factory results.

IRRIGATION DEVELOPMENT IN NORTH DAKOTA.

By H. A. Storrs.

Surveys and examinations of the entire arid portion of North Dakota have been pushed systematically and energetically by the Reclamation Service in the effort to discover a locality where the natural conditions offer a fighting chance of working out a feasible irrigation project. The topographic features of the State are, however, distinctly unfavorable to the storage and diversion of water from its streams, and North Dakota seems to possess few, if any, possibilities of large irrigation projects.

The Missouri affords an abundance of water, but the irrigable lands along its banks exist either in small tracts at low elevations, or in extensive plains at high elevations above the river. The lower lands are not sufficient in extent at any location to warrant the enormous expense involved in damming and diverting the waters of the Missouri. The higher lands could be reached only by dams of great length and height or by large canals several hundred miles long. Neither of these methods is considered feasible, in view of the unfavorable topographic features presented and the enormous expense involved.

The smaller streams are flat in slope, variable in flow, devoid of favorable reservoir sites, and hemmed in by high banks of earth, all of which conditions are unfavorable to storage or diversion of irrigating water on a large scale. The conditions, however, on most of the streams west of the Missouri are distinctly favorable to small dams and pumping plants which private enterprises will no doubt utilize in the near future.

During the past season it was determined to ascertain whether it would be feasible to pump water from the Missouri for irrigating the inviting bench lands which extend for many miles along its banks. The Reclamation Service has been unwilling to resort to this method of securing irrigating water, on account of its presumed high cost, if any cheaper or simpler method could be discovered. The feasibility of any pumping project is not assured until it is demonstrated that the value of the lands and crops will warrant the necessary expenditure for pumping machinery, canal system, and annual operating expenses.

The engineer can determine the natural conditions, the cost of irrigation works and their maintenance and operation, and can present figures showing the cost per acre for irrigating a proposed tract of land. It then rests with the land owners to decide whether they will agree to pay what is required to install and operate the proposed irrigation works.

The people of North Dakota have much to learn regarding value of irrigation. Almost no irrigation has been attempted far, and the majority of farmers have had no opportunity to see has been accomplished in other States. Undoubtedly when the as to the increase in the amount and value of crops to be secure means of irrigation are presented to and understood by the p they will be as ready to accept the conditions and secure the be resulting from reclamation projects as have been the farmers in tana and other Western States.

As a result of preliminary investigations not yet completed Reclamation Service will soon present to landowners in the vic of Bismarck, Buford, Trenton, and possibly some other localities proposition to erect pumping plants at these places, provided people will agree to cooperate in the enterprises.

The costs promise to be but little if any higher than for man the projects in other States, where an annual charge of $3 to $4 acre is required during the first ten years. This amount pays fo irrigation works in ten annual installments, in accordance with terms of the reclamation act, and also pays the cost of opera expenses during the first ten years. During subsequent years annual charge covers only maintenance and operating expenses.

In projects involving steam or gas-engine pumping plants operating expenses will probably be greater than on gravity syst These operating expenses, however, will be approximately pro tional to the amount of water actually pumped. Consequently years of heavy rainfall the operating expenses will be small. pumping plants are really a reserve, to be called upon to supply deficiencies of rainfall and run-off. By storing all the flood wa of small streams within the area covered by the project the run may materially lessen the quantity of water which has to be pum

In general it may be stated that the pumping works and ca systems for the two projects examined would be paid for in annual payments not exceeding $2 per acre each. The maintena charges would involve an additional annual payment of about $1 acre and would be practically constant, whether much or little i gating water was used. The operating expenses would, howe vary according to the amount of water actually used, and wo amount to little or nothing during years of abundant rain During dry years, when as much as 2 acre-feet per acre might be u the total for maintenance and operation would approximate $2 acre. The pumping plants will have a capacity of 2 acre-feet per a for the entire tract during an irrigation season one hundred day length. On this basis the probable annual operating expenses h been estimated. This amount is probably the maximum that wil required if economy is exercised in the use of water.

The Buford-Trenton project includes about 18,000 acres and the Bismarck project about 15,000 acres. Both projects are on the left bank of the Missouri, the former near the Montana State line and the latter south and east of Bismarck. The latter may be considerably extended after the surveys are completed and the results studied. Possibly it will be thought advisable to erect a central power station convenient to the coal supply and transmit the power electrically to the pumping plants, thus saving transportation of coal to pumping plants located at a distance from the railroads or coal mines. In any event the landowners along the Missouri, and possibly other rivers in the State, will soon have an opportunity to signify their desires regarding the construction of national irrigation works within the confines of the State.

RECORDS OF FLOW AT CURRENT-METER GAGING STATIONS DURING THE FROZEN SEASON.

By F. H. Tillinghast.

GENERAL WINTER CONDITIONS.

In the determination of the volume of flow of rivers for conditions of open channel at the ordinary current-meter gaging stations, the methods of the United States Geological Survey are well defined and the limits of accuracy are known to be reasonable. For ice conditions, on the other hand, records of gage heights are not uniform, knowledge of the relation of gage height to discharge is meager, and estimates of flow are often much in error.

Throughout the Northern States the most severe droughts occur in the winter months. Whenever the streams are closed by ice with a low condition of ground water, if the period of cold is long continued, there is sure to result a period of extremely low stages of the rivers; for during the frozen season no surface water finds its way to the streams, the precipitation being all stored in the form of snow. One or two such periods of low water have been known in which there has been a draft upon the ground water covering a period of nearly six months, and the streams have discharged a smaller amount than has been recorded with open-channel conditions.

It is, therefore, very desirable that a full investigation should be made of the whole subject of flow of water under ice, in order to determine the best methods for making discharge measurements, the gage height to be used, and the probable accuracy of the results. None of these matters have received adequate attention and there are comparatively few data bearing upon the subject.

The winter conditions in many rivers vary through a large range, from those which may be called normal, in which the ice remains

practically in the position in which it has formed and the stream is quickly closed by a uniform cover of ice, to those where the ice has been broken and is either flowing in large blocks, often practically filling the whole section of the river, or has been gorged to form temporary dams. To these latter cases no general rules can apply; each must be considered as a problem by itself.

With unbroken ice, fair estimates of flow are possible. There is, however, a wide range in so-called normal conditions of ice through all stages in ice development, from the first fringe along the shore to the solid cover of smooth ice varying in thickness to a maximum of 30 or even 40 inches. With a falling stage of the river the ice cover may not rest entirely on the water, but may act in part as a bridge supported on the banks; on the other hand, with a rising stream the pressure of the water under the ice may be greater than that due to the weight of the ice.

FLOW UNDER ICE.

There have been made several series of current-meter measurements of flow under ice by the hydrographers of the United States Geological Survey. The measurements have been tabulated according to increasing gage heights and compared with discharges as obtained from the open-section rating table, as shown below:

Discharge measurements, with ice conditions.

Gage height to water surface.	Thickness of ice, in feet.	Average depth of water below ice.	Actual discharge (closed section).	Discharge from rating table (open section).	Coefficient for reducing open section to ice conditions.
WALLKILL RIVER AT NEWPALTZ, N. Y.					
7.14	1.1	5.4	332	805	0.41
7.23	2.0	4.6	288	855	.34
7.68	1.1	6.0	597	1,105	.54
8.75	1.0	7.2	945	1,765	.54
8.97	1.0	7.4	1,167	1,910	.61
10.80	1.0	9.2	2,028	3,250	.62
11.10	.8	9.2	2,293	3,494	.66
[a] 11.40	.....	.....	3,040	3,746	.....
[b] 13.60	.....	.....	3,277	5,660	.....
[a] 15.75	.....	.....	5,985	7,650	.....
17.23	.9	15.5	6,063	9,170	.66

[a] Partly open channel. [b] Ice piled along banks.

Discharge measurements, with ice conditions—Continued.

Gage height to water surface.	Thickness of ice, in feet.	Average depth of water below ice.	Actual discharge (closed section).	Discharge from rating table (open section).	Coefficient for reducing open section to ice conditions.
RONDOUT CREEK AT ROSENDALE, N. Y.					
[a] 6.63	0.3	5.6	222	302	0.73
[b] 6.83	.....	.....	423	434	.....
[c] 7.43	.....	.....	772	910	.....
[b] 7.50	.7	6.0	342	971	.35
7.93	1.5	5.7	543	1,402	.39
7.96	.5	6.8	676	1,432	.47
8.61	.2	7.7	1,185	2,120	.56
ESOPUS CREEK AT KINGSTON, N. Y.					
[a] 5.25	0.3	2.9	245	322	.....
[a] 5.47	.3	3.1	337	376	.....
6.30	.1	4.4	476	631	0.75
[a] 6.43	.1	4.2	522	675	.....
6.60	.8	4.0	425	741	.57
6.70	.3	4.3	530	782	.68
[a] 6.80	.4	4.6	654	823	.....
[a] 9.01	.3	6.8	1,687	1,947	.....
12.70	.4	10.8	3,461	5,008	.68
FISHKILL CREEK AT GLENHAM, N. Y.					
[d] 4.25	0.4	3.5	100	300	0.33
4.87	.5	4.0	202	554	.37
5.00	.5	4.0	261	615	.43
CATSKILL CREEK AT SOUTH CAIRO, N. Y.					
[a] 3.30	0.4	2.5	110	120	0.91
[a] 3.50	.8	3.0	148	152	.97
4.72	1.0	3.0	363	660	.55

[a] Partly open channel.
[b] Anchor ice.
[c] Ice piled up along banks.
[d] Water backed up.

Discharge measurements, with ice conditions—Continued.

Gage height to water surface.	Thickness of ice, in feet.	Average depth of water below ice.	Actual discharge (closed section).	Discharge from rating table (open section).	Coefficient for reducing open section to ice conditions.
CONNECTICUT RIVER AT ORFORD, N. H.					
4.03	2.0	5.0	799	1,765	0.45
4.03	2.0	5.0	790	1,765	.44
4.08	2.0	5.0	785	1,800	.44
4.12	1.9	5.0	876	1,820	.48
4.15	1.9	5.0	884	1,845	.48
4.20	2.0	5.0	792	1,880	.42
6.60	1.2	7.0	2,620	4,120	.63
6.90	1.4	7.0	2,690	4,450	.61
7.20	1.2	7.0	2,970	4,780	.62
7.40	1.4	7.0	2,980	5,000	.60
7.45	1.4	7.0	2,990	5,055	.59
7.45	1.4	7.0	3,030	5,055	.60

VELOCITY OF FLOW.

The results of these measurements have been studied to ascer the effect of the ice cover upon (1) the vertical distributio velocity, especially upon the position of the point of mean velo and (2) the ratio of gage height to discharge as compared that ratio for open-channel conditions.

Observations were taken through holes cut in the ice at reg distances across the stream. Velocities were obtained at ten or points in the vertical and were plotted on cross-section paper. depths as ordinates and velocities as abscissæ. A curve was d through the points so determined and divided into ten parts. center velocities of each part, taken from the curve, added divided by 10 gave the mean velocity in that section.

When the holes were cut the water rose nearly flush with surface of the ice, showing that it was flowing under pressure study of the tables and curves showed that the flow of water u such conditions was somewhat similar to its flow in pipes an closed flumes. The mean velocity occurred at two points in vertical, the average of 101 curves (see table below) being at depth and 0.71 depth; the maximum velocity occurred at 0.36 de The curves dragged more for shallow depths and became more cave, and consequently the error of observation increased if meter was not held at the proper point in a vertical.

Position of mean and maximum velocities in a vertical plane under ice.

Depth from under surface of ice, in feet.	Number of curves.	Depth of mean velocity.		Depth of maximum velocity.	Coefficient to reduce maximum to mean.
WALLKILL RIVER, NEWPALTZ, N. Y.					
[a] 4 to 12	20	0.12	0.71	0.38	0.85
[b] 4 19	26	.13	.74	.38	.86
ESOPUS CREEK, KINGSTON, N. Y.					
[a] 2.3 to 7.4	16	0.08	0.68	0.36	0.80
[b] 5 8	8	.11	.73	.37	.85
RONDOUT CREEK, ROSENDALE, N. Y.					
[a] 4 to 8	5	0.08	0.68	0.35	0.82
[b] 5 7	8	.13	.71	.35	.86
CONNECTICUT RIVER, ORFORD, N. H.					
[c] 2.5 to 7.7	18	0.11	0.69	0.35	0.85
MEAN.					
.....	.....	0.11	0.71	0.36	0.84

[a] By F. H Tillinghast. [b] By W. W. Schlecht. [c] By C. A. Holden.

ICE-RATING COEFFICIENTS.

Results of the discharge measurements, given in the first table, have been platted on the sheet which contains the rating curve for open-channel conditions, using first the gage height to the surface of the water and second the gage height to the bottom of the ice. The results when platted with gage heights to the surface of the water have been more consistent among themselves and have located a curve approximately parallel to the curve for open-channel conditions, and lying always to the left of it. The results when platted with the gage height at the bottom of the ice have not been consistent among themselves and the curve, which is not so well defined as in the first case, crosses the rating curve for open-channel conditions, falling to the right of it in the lower part and to the left of it in the upper part.

From the data at hand, therefore, it appears to be best to u
heights to the surface of the water as it rises in the hole cut
ice, and a comparison of the ice-rating curve so platted wi
open-channel rating curve is given in the following table:

Relation between discharges from open-section and ice-rating curve

Gage height.	Discharge from ice-rating curve.	Discharge from open-section rating curve.	Coefficient for reducing open section to ice conditions.	Mean coefficient.	Greatest range from mean coefficient.	Weigh given result
WALLKILL RIVER AT NEWPALTZ, N. Y.						
8.0	650	1,290	0.50			
9.0	1,125	1,930	.58			
10.0	1,640	2,630	.62			
11.0	2,180	3,410	.64			
12.0	2,760	4,250	.65			
13.0	3,360	5,120	.66	0.63	0.13	
14.0	3,980	6,020	.66			
15.0	4,610	6,940	.66			
16.0	5,240	7,890	.66			
17.0	5,920	8,930	.66			
18.0	6,575	10,000	.66			
RONDOUT CREEK AT ROSENDALE, N. Y.						
8.0	688	1,472	0.47			
8.5	1,040	2,000	.52			
9.0	1,425	2,539	.56	0.55	0.08	
9.5	1,840	3,102	.59			
10.0	2,290	3,700	.62			
ESOPUS CREEK AT KINGSTON, N. Y.						
6.0	320	527	0.61			
7.0	625	905	.69			
8.0	1,010	1,373	.74			
9.0	1,470	1,940	.75			
10.0	1,980	2,642	.75	0.71	0.10	1
11.0	2,520	3,440	.73			
12.0	3,075	4,340	.71			
13.0	3,650	5,305	.69			

Relation between discharges from open-section and ice-rating curves—Continued.

Gage height.	Discharge from ice-rating curve.	Discharge from open-section rating curve.	Coefficient for reducing open section to ice conditions.	Mean coefficient.	Greatest range from mean coefficient.	Weight given results.
FISHKILL CREEK AT GLENHAM, N. Y.						
4.2	140	284	0.49	0.53	0.04	1
4.5	210	380	.55			
4.8	280	521	.54			
5.0	330	615	.54			
5.2	400	737	.54			
CATSKILL CREEK AT SOUTH CAIRO, N. Y.						
4.72	363	660	0.55	0.55	0.55	1
CONNECTICUT RIVER AT ORFORD, N. H.						
4.0	800	1,740	0.46	0.57	0.11	1
4.5	1,100	2,110	.52			
5.0	1,400	2,520	.56			
5.5	1,700	2,970	.57			
6.0	2,050	3,470	.59			
6.5	2,400	4,010	.60			
7.0	2,750	4,560	.60			
7.5	3,100	5,110	.61			
8.0	3,500	5,660	.62			

Total mean coefficient, 0.595, or about 0.6.

In the table above are given the values of the coefficient, which must be applied to the rating curve for open-channel conditions in order to give an estimate of discharge under ice when the gage is read to the top of the water. It will be noticed that the coefficient to be used varies between 0.46 and 0.75, with a mean of 0.60. Isolated measurements have been made with thicker ice and comparatively small depths which give coefficients as low as 0.30. If ice conditions are not known in detail, therefore, an estimate based on a coefficient of 0.60 would probably be most nearly correct. It seems probable that further investigations will enable us to determine upon a sliding coefficient, varying between 0.30 and 0.75, the value of which for each case shall be determined by the thickness of the ice or by the ratio of the thickness of the ice to the depth of water, and from which we can obtain more reliable estimates.

CONCLUSIONS.

It is urged that in making measurements of flow under the i the future the record be made as complete as possible. The ve velocity method should be used and data accumulated in rega the nature of the ice at the section and above and below it, the height of the water as it stands in a hole cut in the ice, the gage h of the bottom of the ice, the thickness of the ice, and any other at ant conditions which may even remotely affect the discharge, in that in further study of this subject all possible information m at hand.

BOOKKEEPING FOR RECLAMATION SERVICE.

By N. E. Webster, Jr.

GENERAL CONDITIONS.

In the matter of a system of bookkeeping for the hydrogra branch, study has first been given to the problems presented in reclamation fund because of the unusual conditions which atta it and which make necessary such methods as will enable the Se to report at any time the amount of expenditures and liabilities a certain lines. It has also been thought that any plans which w succeed with the accounts of the Reclamation Service could easil adapted to those of the appropriation for gaging streams, elimina such features as would be inappropriate or undesirable.

But while it seems wise to have the accounts of the two approp tions as similar in forms and method as possible, because they ar largely prepared and handled by the same persons, it seems also they should be made readily distinguishable, and for this pur that all blank forms affecting the accounts of the Reclamation S ice, as vouchers, charge sheets, debit and credit notices, bills of lad etc., should be issued on paper of a distinctive color.

In the report of the committee on costs and results[a] such refer has been made to the bookkeeping of the Service as was necessar make clear the operations required of the engineers in the field. local accounts and those in the Washington office should be desig upon the same general plans, the former showing in greater detail what features of the various projects the expenditures have b made, and the latter giving a comprehensive exhibit of the resour expenditures, and liabilities of the entire Service. In attempting latter especial attention should be given to the language of the re mation act, that the accounting may follow the lines therein down. The law states that the fund is derived, first, from the sale

[a] See pp. 162–173.

public lands, etc., and, second, from the return of construction charges; that it is to be distributed so as to expend the major portion in the State where it arose; and that it is to be applied in "examination, survey, preparation of maps and plans (designing), limiting area of entry (subdividing), acquisition of rights and property, construction, maintenance and operation of irrigation works," and in other expenditures provided for (executive). There are, besides, the departmental and bureau regulations relative to accounts, which must be observed.

BOOKKEEPING IN WASHINGTON.

STATE RECORD.

As section 9 of the reclamation act declares it "to be the duty of the Secretary of the Interior, in carrying out the provisions of this act, so far as the same may be practicable and subject to the existence of feasible irrigation projects, to expend the major portion of the funds arising from the sale of public lands within each State and Territory hereinbefore named within the limits of such State or Territory: *Provided*, etc.," it is necessary to keep a record of the reclamation fund by States and Territories.

In this will be entered temporarily the approximate amounts arising from the sale of lands and the collection of construction charges in the reclamation States as reported annually, following the close of each fiscal year, by the Commissioner of the General Land Office, subject to such correction as may be necessary when the public-land accounts have been audited by the accounting officers of the Treasury Department and reported on by them. Of these amounts 51 per cent is restricted to each State as the "major portion" of such fund.

As charges against such credits will be entered the estimated costs of the distinct projects which have been determined upon and authorized by the Secretary of the Interior, the amount being subject to revision upon completion of the project, so as to equal the actual costs.

PROJECT RECORD.

As section 4 states that "the charges which shall be made per acre upon the said entries, and upon lands in private ownership which may be irrigated by waters of the said irrigation project, * * * shall be determined with a view of returning to the reclamation fund the estimated cost of construction of the project," and as section 5 states that "the entryman upon lands to be irrigated by such works * * * shall pay to the Government the charges apportioned against such tract as provided in section 4," a record of the charges against each project is required.

For this there should be a project ledger in which shall be segregated all the credits and charges to and against individual projects and all charges against reconnaissance in States where no project has yet been developed, the several accounts under one State being grouped together and the States arranged alphabetically. The accounts for the various projects within a State should be entered, not alphabetically, but in the order of their adoption as definite projects, and for convenience in cross reference should be given a number indicating the order in which they have been taken up. The Washington office should be treated as a State, and its cost finally distributed over the entire Service.

On the title-page of each project account should appear the name of the State under which the account is being carried, the name of the project, its number and the date of its adoption, its location and extent, the estimated acreage to be reclaimed, and if the work undertaken or the lands to be reclaimed lie in two or more States the name of each of such States, with its estimated proportion of expense and benefit, should be given. The contracts let for construction, etc., may here be recorded, thus showing in a concise form what are to be the larger items of expenditure on the project.

As credits to the several projects will be entered the authorization of the Secretary of the Interior for the construction of the works at the estimated costs, and subsequently any amounts arising from the charging to other projects of equipment, material, or supplies transferred, or of the expense of Washington office administration previously prorated against the then existing projects. All credits which do not increase the total amount available, but decrease the expense incurred, should be entered in red ink and deducted from debit totals, which will then show the actual cost of the project.

As charges against the several projects will appear the expenditures thereon for which vouchers have been approved, the ledger showing the number of the charge sheet for the voucher and the amount thereof.

Following the sheets on which are entered the charges against the project should be others with the titles of the secondary charges of the charge sheet—examination, survey, design, subdivision, rights and property, construction, maintenance, operation, and executive; and these auxiliary sheets should have nine vertical subdivisions in which to enter the tertiary charges of the distribution of the expense under the headings services, traveling, subsistence, equipment, materials, supplies, rent and storage, forage, and construction contracts, each subdivision having two columns for charge-sheet number and amount.

All the columns of this project ledger should be totaled separately in order that any necessary corrections of the vouchers or the distribu-

tion thereof, made after entry in this ledger, may be corrected on the original entry without changing every subsequent footing.

VOUCHER RECORD.

There should be a voucher record in which the approved vouchers should be entered each day under the proper headings, date, charge sheet, and voucher numbers, in whose favor drawn, amount, to what project chargeable, and how payment was made—as by whom, date, and check number. Every voucher should be accompanied by an appropriate charge sheet. Vouchers paid by local disbursing officers will be received in Washington with their accounts therefor, and the only entries necessary under payment will be name of disbursing officer and date of payment. Vouchers to be paid by the disbursing officer in Washington will be indicated as sent to him. Vouchers to be paid by warrant from the Treasury Department will be noted "Treas."

CHARGE SHEETS.

A separate charge sheet should be prepared for and accompany each voucher to the Washington office. If a voucher is received without a charge sheet, the clerk examining the voucher should prepare a "dummy," inserting all the information obtainable from the voucher, and write the engineer to forward a proper charge sheet, which may be substituted when received. It should show the number and date of the voucher, in whose favor drawn, amount, and by whom payable, and be signed by the officer approving the account.

When these sheets are received in the Washington office the clerk examining the voucher should, before passing it, give both voucher and its charge sheet a serial office number, with a numbering stamp set to "duplicate," this number to be the one under which the voucher is to be entered in the voucher record before described, and to be used in the ledger postings referred to under the project ledger. When the postings from the charge sheet have been made, the clerk making them should initial it, thus indicating what work has been done on it.

The postings to the project ledger, both to the general project account and to the distribution sheets therewith, are to be made from the charge sheets, which should then be bound in books of probably 500 sheets, each arranged in the order of the numbers thereof, the book to be so labeled as to show the numbers of the charge sheets contained in it and the dates when the first and last vouchers covered by them were entered in the voucher record.

DEBIT NOTICE.

Whenever a debit upon a paid voucher arises against a definite project from without the office of the resident engineer, or against

the reconnaissance account of a State from without the office of the engineer in charge, debit sheets should be prepared in the Washington office, showing the amount of such charge, how it arose, to whom payable, and the distribution as far as possible, and one each be sent the engineers whose accounts are affected and one retained in the Washington office and filed with the charge sheet covering the voucher to which it pertains.

CREDIT NOTICE.

Whenever a credit arises to a definite project from without the office of the resident engineer, or to the reconnaissance account of a State from without the office of the engineer in charge, credit sheets should be prepared in the Washington office, showing the amount of such charge, how it arose, from whom repayable, and the distribution originally made of the charge when vouchered, and one each be sent to the engineers whose accounts are affected and one retained in the Washington office and filed with the charge sheet covering the voucher to which it pertains.

TRANSFER SHEETS.

Whenever charges made against one account are to be reentered against other accounts, as upon the shipment from one project to another of equipment, materials, or supplies, or upon the prorating against various projects of the general accounts of a State or of the Washington office, transfer sheets in triplicate, or in quintuplicate if necessary, should be prepared in the office where the new debit originates, showing the amount of such charge, how it arose, a description of the subject-matter of the transfer, and the distribution originally made of the charge when vouchered, and one each be sent to all the offices affected and one to the Washington office.

In the Washington office such a transfer sheet should be given the same serial number as that of the charge sheet it follows in the file, and the postings should show this number preceded by the letter "T."

JOURNAL-DAYBOOK.

It is believed that the charge sheets, debit notices, credit notices, and transfer sheets when assembled and bound together will constitute a complete journal-daybook and be the book of original entry.

BOOKKEEPING AT PROJECT OFFICES.

On June 7, 1904, a circular letter was sent to all engineers regarding methods of bookkeeping. This letter contemplated bookkeeping based on the charge sheet then in use (Form 9-272) and provided that

each secondary charge should be given a page of the ledger. It showed how any ordinary ruled blank book could be adapted to this use by ruling additional columns. The tertiary charges for which columns were thus provided were "services, traveling, subsistence, equipment, office, supplies, storage," and there was a column for totals and two blank columns. It was intended that a portion of the ledger should be set aside for each of the secondary charges.

Under the new charge sheet (Form 9-501) there are two more tertiary charges than under the former one, but two of these, "materials" and "construction contracts," apply to the secondary charge of construction only, so that a ledger which would carry the former distribution can be readily adapted to the new one, placing the charges to "office" against "services, equipment, or supplies," according to the nature of the expense, and using that column for "forage."

If the books as already ruled provide for nine columns, that will take all the tertiary charges now used. If only seven were provided, another blank page, following the one provided for the secondary charges of construction should be used for the tertiary charges of "materials and construction."

The secondary charges of "topography, testing, and design" under the former analysis are now united in the one charge of "survey," and the totals of the three accounts should be taken as the initial balance when beginning with the new distribution.

For "maintenance and operation" no accounts need be opened until some portion of a project is completed and being operated.

Attention is called to the instructions for keeping accounts of stores (Form 9-508) which will require that all vouchers for stores be charged first to an appropriate account of the stores ledger, as "equipment," "materials—cement," "supplies—fuel," "supplies—lumber," "subsistence—heat," etc., and then charged to the proper secondary charge as issued. The balance of these stores accounts at any date will represent the stocks on hand and must be taken, together with the totals of the several secondary charges, to equal the total of the vouchers approved for payment.

As stores are purchased it will be necessary to prepare a charge sheet covering the voucher, in which the whole amount of the voucher will be placed against one or more of the secondary charges. At the project, however, a more accurate record can be made by placing the charge for such vouchers to accounts in the stores ledger and making the debit to the proper secondary charge only as issued.

This will admit also of subdividing a project into its principal features, and keeping, at the project, an account with each, as in Washington an account is kept with each project.

usual firm or company name, followed by the autograph signature, with his title, of the partner or officer authorized to receive the money.

The vouchers should bear the certificate of the engineer incurring the expense that the account is correct and just; that the articles specified have been received by him, or the services stated have been performed; that they were necessary for and have been or will be applied to the purposes contemplated by the reclamation act; and, in the case of other than personal services or reimbursements for expenses, that to the best of his knowledge and belief the prices charged are reasonable and just, and that they were supplied in such and such a way, with reference to methods of contract and of securing competition. This last must show whether the purchase was under contract or under an informal agreement, with immediate delivery or performance. It must also show whether the purchase was upon competitive proposals in accordance with and after advertising in so many newspapers, or by circular letter sent to so many dealers and posted in so many places; or upon noncompetitive quotations without advertising, under an exigency of the service existing prior to the order, which would not admit of delay incident to advertising, or by reason of impracticability to secure competition because of certain specified causes.

Vouchers for reimbursement for traveling expenses should contain a certificate showing that the travel was made upon competent orders. They should also be supported by subvouchers, as provided in Regulations of the United States Geological Survey, 1903, section 45, paragraph 3 (1), as amended January 18, 1905.

Vouchers for payment in pursuance of contract for construction should show in detail the estimates of all work done or material delivered to the date of the voucher. The items should be listed in the order and under the designations given in the contract. A summation of these items will show the value of the work done or material delivered to date, from which there should be deducted the percentage which the contract provides as a holdback and the amount of previous payments.

If extra work is to be paid for, that portion of the voucher should be prepared in the following form:

EXTRA WORK.

Labor and materials, as per attached itemized statement:

Actual cost of labor and materials, ———, $———; —— per cent added, as per paragraph —— of contract, ———, $———.

To the voucher should be attached:

1. Itemized statement of labor and materials, with engineer's certificate as follows:

I hereby certify that the above statement of cost of labor and materials is correct, and that the said extra work was performed in accordance with my instructions, dated ———, 190—, and that the same has been satisfactorily performed.

2. Copy of letter to contractor authorizing the extra work.

Accounts for amounts due contractors for construction should bear the certificate of the engineer immediately in charge of the work done that—

I have inspected for the Reclamation Service the work and materials described in the foregoing, and find that the same are in conformity with the contract and specifications and are of the value stated. I further certify that the stipulations thereof have been complied with up to the present time.

Also, the following certificate of the supervising or district engineer in executive charge of the project:

I certify on honor that the foregoing account is correct and just; that the work and materials have been carefully inspected by ——— ———, who signed the preceding certificate; that the stipulations of the contract and specifications have been complied with, as is stated in the foregoing certificate; and that there is now due upon this claim the sum of $———, no part of which has been paid.

When properly prepared, all vouchers should be forwarded through superior engineers for payment.

PAYMENT.

This will be effected in one of three ways: First, by a local disbursing officer located at the project or in the office of the supervising engineer; second, by the chief disbursing clerk of the Geological Survey at Washington; or, third, as in the case of vouchers for amounts found due for freight, etc., by a warrant drawn by the Secretary of the Treasury on the certificate of the Auditor for the Interior Department.

In the first case the local disbursing officer retains one voucher as evidence of payment and forwards the other to the chief engineer, either with his abstract at the end of the quarter or with a request for a renewal of his credit to the amount of such vouchers should his balance become so low as to necessitate such action.

In the second and third cases, where the account is to be paid from Washington, both vouchers after being approved by the supervising engineer are forwarded to the chief engineer. In the Washington office all vouchers are carefully examined for mistakes and informalities, and if found correct are certified by the chief engineer and approved by the Director, and go to the chief disbursing clerk

of the Geological Survey. All vouchers which have not already been paid by local disbursing officers are paid from the latter's office, except those for amounts due for freight and express on Government bills of lading; for passenger fares on Government transportation requests over bond-aided railroad lines; for cartage in Washington on contract with depot quartermaster, United States Army, and for amounts due for purchases or construction so large as to make it inadvisable to so greatly exhaust his credit balance. He retains one of the duplicate vouchers as evidence of payment.

All three classes of vouchers are then sent to the chief disbursing officer of the Department of the Interior, whence all go to the office of the Auditor for the Interior Department. This is a bureau of the Treasury Department, and here all the accounts are audited and allowed, suspended, or disallowed. The accounts not previously paid, as for freight, etc., are examined, and if approved are certified to the Secretary of the Treasury, who draws warrants in payment therefor upon the Treasurer of the United States. For each disbursement from the reclamation fund or other appropriation a voucher must be submitted to the Auditor for his permanent record. When necessary, such vouchers may be consulted upon proper application, as may also those in the possession of the several disbursing officers.

SUSPENSIONS AND DISALLOWANCES.

Exception to the propriety of any account may be noted by any of the various officers who pass upon it, but any such objection will fall in one of two general classes—those made by administrative officers and those made by auditing officers.

Should any certifying or approving officer object to the subject-matter or amount of any voucher which is submitted to him, he will call upon the payee or certifying officer for explanation, suspending the entire account or that portion covering the items questioned. If the account is not satisfactorily explained, the objectionable items must be withdrawn, and any payments made thereon must be refunded to the disbursing officer.

Should the Auditor in his examination of the accounts of any disbursing officer take exception to any of the payments for which credit is claimed, such objections will be made in one of two ways. The first method is by a suspension of the items questioned, when the disbursing officer is called upon for an explanation of these items. In order to reply to such a notice of suspension the disbursing officer will usually have to call upon the engineer approving the account for the necessary information. Such explanations should be made promptly, and in any event within six months from the date of suspension, for

if no explanation of the suspended items is made within that period they are subject to disallowance. The second method of noting exceptions to an account is by a disallowance of the items questioned, and for this an explanation to the Auditor is not sufficient. To secure a revision of such disallowance request should be made to the Comptroller of the Treasury, and within one year from the date of the Auditor's settlement. The Comptroller's decision is final upon executive branches of the Government, but an appeal therefrom on behalf of the claimant will lie to the Court of Claims.

TIME REQUIRED FOR AUDITING.

From the foregoing it is evident that a period of several months must elapse after the approval of account before final action will have been taken thereon. This period will vary greatly in different cases, and no certain date can be fixed in advance when an account will be closed. When a voucher is complete and apparently correct, there will be but little time required in the offices of the project, supervising, or chief engineers. It may remain in the disbursing offices after payment from a day to three months, but should be received in that office by the 20th of the month following the end of the quarter, and must in any case reach the office of the Auditor by the 20th of the last month of the succeeding quarter. It will be from three to fifteen months in this office before a report may be expected from the Auditor, and in the case of suspensions or disallowances thereafter no period of time can be stated.

REQUESTS FOR RULINGS.

In order, therefore, to avoid delay in settlement of accounts, and their subsequent disallowance upon revision, it is important to see to it in advance that all vouchers are for proper and authorized expenditures. Whenever there is doubt, an opinion can always be obtained, either in advance by the engineer upon application through his superiors and the chief engineer to the Secretary of the Interior or by the disbursing officer upon the presentation to him of the account for payment, by application through the proper channels directly to the Comptroller. So far as possible the former course should be followed in order to avoid the incurring of unauthorized or improper expense, but when this is impracticable the disbursing officer, when called upon for payment of an account containing charges for unprecedented or questionable items, should always submit the account to the Comptroller for an opinion as to its propriety under existing law.

REPORTS OF COMMITTEES OF THE CONFEREN

The following are the reports of the various committees, practi as rendered by the committees, the modifications, if any, being such as to enable the chief engineer to approve the reports as a w

COMMITTEE ON CEMENT AND CONCRETE.

REQUIREMENTS AT THE SALT RIVER PROJECTS.

The cement specifications prepared by the committee at its me in Los Angeles December 26, 1903, have been followed by the De ment in purchasing cement for the several projects in Nevada, I and Arizona, and the particulars may be found in the proposals contracts for cement used in the constructions under way in t States.

In the summer and fall of 1904 the Service established laborat for testing cement at Berkeley, Cal., Denver, Colo., Roosevelt, A and Washington, D. C. Mr. F. W. Huber has had charge of Berkeley laboratory and has tested the cement used on the Tru Carson project. Mr. J. Y. Jewett has conducted the Denver lab tory and has passed on the cement shipped from Portland, Colo Arizona and from Salt Lake to the Minidoka project. The Ro velt laboratory has been under the direction of Mr. E. Duryee, assi by Mr. H. A. Tobleman, chemist. This laboratory is equipped general analytical work and in addition to testing cements has n many analyses for various survey projects and trial burns of cen materials. Some investigations have been conducted in all the l ratories on natural and crushed rock sands that have been of n interest and are likely to lead to economies in the use of cements. Duryee is prepared to make investigations in several lines as to me of reducing the cost of cement for the various projects. This sometimes be accomplished by grinding sand cement at the site of project, or by requiring specially fine grinding of the Portland o making the cement at the site. The chief engineer called upon Duryee for additional details as to methods followed by him in tes cement and received the following suggestions supplementing specifications referred to:

In preparing the specifications and conducting tests of cements aim has been to ascertain, before shipment, the quality of the cen offered by the contractor. The requirements of the specification

o aging for a period of two months, and sampling and testing at he cement works before shipment, may appear to be rather exact-ng, but in the long run these provisions work to the advantage of oth manufacturer and purchaser. The cement manufacturers gen-rally claim that they plan to hold all cement for sixty days before hipment, and the contractor should provide sufficient warehouse apacity to permit storage of the sacked cement for one month, dur-ng the period of sampling and testing.

Sampling.—The samples are kept separate. Every fortieth sack is pened and a fair sample, weighing about 2 pounds, is extracted with sampler. On retying the sack a tag, numbered and dated and aving the car number noted thereon, is securely attached to the ack by means of wire and lead seals, fastened with a car sealer. The sample of cement is put into a paper sack numbered to corre-pond with the sample tag.

In bulk, in a bin, cement cures very slowly and may vary considera-ly in quality. On this account it is better to have the cement sacked efore sampling. The tester can then sample more fairly, the cement will cure better, and the shipments can be more surely identified when the sealer is used. The Service sealer has the initials U. S. R. n the die.

Tests.—In a general way the rules for testing adopted by the Amer-can Society of Civil Engineers and the American Society for Testing Materials, which can be found in the transactions of those societies, are followed. It is advisable for the tester to submit his pinions of the cement as tested, with his report, the judgment to be ased on the results of his tests, and he should not allow any cement o be shipped that is not sound, safe, and high-grade Portland.

Screening.—A screening test of a mixed average sample from each ar is made in the laboratory. The cement from some factories aries greatly in fineness as well as in strength, and on that account t is well when time permits to make screening tests on individual amples instead of on a mixed sample, so as to show if there is much ariation.

Consistency.—A preliminary and approximate test is made by nixing a small quantity of cement with a measured portion of water; he mortar is then worked for three minutes, molded with the hands nto a ball, and dropped from a height of 20 inches. If the proper roportion of water is used, the ball will not crack. The test is onfirmed by using a Vicat needle in the manner described in manuals n cement testing.

Making pats.—Three ounces of cement are mixed with sufficient water to give a paste of normal consistency. The cement is weighed ut the water is usually gaged in a glass graduate, the quantity used

being approximately 25 per cent. The water is added to the cement in one dose and the mortar is then worked with a trowel for two minutes. Standard specifications usually mention five minutes, but two minutes is about as long as laboratory practice allows. One pat is made from each sample. As soon as made the pat is put in a moist atmosphere. This can be obtained by suspending wet crash towels over a light wooden frame, if no better arrangement can be made. As often as necessary the pat is removed and tested with a one-fourth pound Gilmore needle for the initial test. After standing twenty-four hours these same pats are put in a pan and water of the temperature of the room is poured over them and gradually raised to the boiling point and kept at that temperature for six hours. The pats should not soften or crack.

RECOMMENDATIONS OF THE COMMITTEE.

The committee has to report that Mr. Duryee's recommendations have been carefully considered and are recommended for approval.

In the matter of long-time tests of cement and cement mortar, the committee recommends that a series of such tests be undertaken in connection with the construction of the more important dams. The aim should be to undertake only such tests as it is desired to cover a period of one year or more. However, it would be well to keep constantly on hand a limited number of briquettes for short-time tests to be utilized for explanatory and educational purposes.

In addition to the regular tests of neat cement and cement mortar using standard sand, a similar series of tests of cement mortar using samples of sands and broken-stone screenings actually used in the construction should be undertaken in order to determine the relative strength of mortars made with ordinary sands and with broken-stone screenings.

Finally, it is recommended that as far as practicable all tests should be conducted in accordance with rules adopted and recommended by the American Society of Civil Engineers and by the American Society for Testing Materials.

COMMITTEE ON COSTS AND RESULTS.

At the Washington conference there was appointed a committee on costs and results, to which was referred the entire subject of costs, both estimated and actual, and which was instructed to consider the necessary records and methods of collecting information, and to recommend forms for such a system. On January 14, 1905, the committee reported as follows, after having received various reports, suggestions, and forms from the chief engineer, from other engineers, and from former committees:

ACCOUNTING.

There are three closely related but distinct operations to be considered:

(1) Preparation of estimates in advance of execution of work.

(2) Bookkeeping, or records of expenditures and liabilities.

(3) Cost keeping, or summation of actual costs of work done.

Section 2 of the act of June 17, 1902, requires that the Secretary of the Interior shall report to Congress at the beginning of each regular session, giving estimates of cost of all contemplated works, also the cost of works in process of construction, as well as those which have been completed. In short, it requires that the Reclamation Service shall make public these important details of actual cost and go clearly on record on these vital matters.

ADVANCE ESTIMATES.

The law thus requires a report on the estimated cost of all contemplated works. There is opportunity for debate as to what constitutes contemplated work, and experience has shown that judgment must be used in not disclosing these estimates in advance of actual receipt of bids from contractors. It is to be assumed that the law does not compel the divulging of information which good business principles require should be kept confidential. The items, therefore, which go to make up the details of the cost of various parts of the project should not be given publicity until after the matter has been approved by the Secretary and bids received.

In the preparation of advance estimates the items of cost which enter into the estimates should be stated in such a way that it will be practicable in the future to check these against the actual expenditures. It is to be assumed that, as a rule, all estimates are to be prepared upon the basis of a unit price for earth excavation, rock work, concrete, etc. This being the case and the units being given it will be possible when the work is built to make direct comparison.

While it is desired to have the assumed cost ultimately borne out by the facts obtained in construction, yet, at the same time, it should be borne in mind that in case of doubt the estimates should be high rather than low. The results upon the public mind are far better if the work is executed within the original estimates, and great credit is usually given to the man or organization executing the work within the limits originally set. If, however, the actual cost exceeds the estimates, either in unit prices or quantities, it is usually difficult to give a satisfactory explanation. The advance estimates on which the Secretary is asked to authorize construction of a project should therefore be prepared with a view to covering the project's proportion of the State and Washington general charges.

The principle stated above should also be observed in the pre tion of the quarterly estimates.

The three amounts given under the heading of each proje account of the quarterly estimates should represent the following

(1) Total expenditures to end of previous quarter, includin expenses for which vouchers were approved during that period.

(2) Expenditures during expiring quarter, including all exp for which vouchers will be approved during the quarter, wi regard to the time when the expense was incurred.

(3) Estimated expenditures for succeeding quarter, which sl be an amount sufficient to cover all expense which it is expected be incurred and all unpaid liabilities of previous quarters.

BOOKKEEPING.

Vouchers.—In the operations of the Reclamation Service, as i public matters, expenditures are made solely upon vouchers pro approved. Each individual voucher, whether large or small, co tutes a unit and is handled and considered as such. The items i vouchers may be distributed or grouped, but the voucher itself an that relates to it is a distinct entity and should be so treated. other words, the step from the voucher to the entry or series of en in the books must be direct, and all further steps consecutive, so starting with the voucher at the beginning or with the final state at the end, it will be possible for a person of ordinary trainin follow forward or backward and trace out or check over all inte diate steps. A method of bookkeeping which does not permit rapid and definite verification will not answer the purpose for w it is intended.

The voucher is ultimately deposited in some safe place, but, the forming the foundation upon which the bookkeeping rests, is always available for quick reference. The first entry or serie entries made from the voucher must be sufficiently clear to enabl future distributions of accounts to be effected. This distribution only be made in most cases by the person incurring the expense or tifying primarily to its propriety. After the first certificatio made the voucher usually passes into the hands of other persons, are less and less qualified by personal knowledge to verify the ma It is therefore required that the person originally certifying to account should indicate at that time, while the matter is fresh in m the item or items to which charges are to be made.

Charge sheet.—The first step in the bookkeeping is the prepara of a charge sheet (Forms 9-501, 9-502, 9-503) covering the amour each voucher and showing its distribution into several element expense. A new form is recommended, having nine subdivis of secondary charges and nine of tertiary charges. The definition the secondary charges are as follows:

Examination: Reconnaissance and all preliminary investigation.

Survey: Topography, testing, and location.

Design: Preparation of plans and detail drawings.

Subdivision: Limiting area of land per entry in the determination of farm units, including examination of the soil.

Rights and property: Acquisition of lands and rights, abstract of title, and recording.

Construction: Building of the project works and of structures, etc., incidental to such building.

Maintenance: Depreciation and repairs on the irrigation works of such a character as to be separable from operating costs.

Operation: Services and supplies for operating the irrigation works and incidental repairs made by operatives.

Executive: Administration and "all other expenditures provided for."

Each secondary charge has nine subdivisions, or tertiary charges, as follows:

Services.—All charges for salaries, annual or monthly, wages by the day or hour, and any other expenditures for personal services only, or for services of men with teams, or horse hire not classed as livery, where the employment is a continuing one at a unit rate.[a] (See Regulations U. S. G. S., 1903, sec. 43, p. 31.)

Traveling.—All charges for railroad fare, street-car fare, stage fare, livery and keep thereof, ferriage, tolls, sleeping- and parlor-car fare, porterage, checking parcels, hotel bills, meals, laundry, telegrams, and other necessary and incidental expenditures directly the result of a journey, and the jurat fee. (See Regulations U. S. G. S., sec. 45, p. 33.)

Subsistence.—All charges, including freight, for meals, rations, food, water, lodging, etc., for men only, when not traveling.[a] (See Regulations U. S. G. S., sec. 62, p. 48.)

Equipment.—All charges, including freight, for nonexpendable property, including public animals. (See Regulations U. S. G. S., sec. 54, p. 41.)

Materials.—All charges, including freight, for expendable property entering into construction and remaining a part thereof.

Supplies.—All charges, including freight, for expendable property used in preliminary and construction work, and wholly consumed therein, fuel, explosives, lubricants, illumination, repairs (including services when combined with "job" charges for repair supplies), stationery, advertising, telephone, telegrams, and miscellaneous expenses not classified elsewhere.[a]

[a] The wages of cooks, which are a part of the cost of subsistence; of men in Government employ engaged in repairs, which are a part of the cost of supplies; of janitors, which are a part of the cost of rent; and of hostlers and stablemen, which are a part of the cost of the care of animals, are all to be entered under "Services."

Rent and storage.—All charges for rent of offices and other buildings, and storage of equipment, material, and supplies, but not pasturage of public animals.[a] (See Regulations U. S. G. S., sec. 51, p. 40.)

Forage.—All charges, including freight, for feed and care of public or hired animals, pasturage, etc.[a] (See Regulations U. S. G. S., sec. 45, p. 33, and sec. 64, p. 49.)

Construction contracts.—All charges for payments to contractors on account of completed portions of construction work (Voucher Form 9-268). This includes both materials furnished and work done, and covers amounts which, if the work were done directly by the Government, would be spread over the preceding eight charges.

A charge sheet should be prepared for and accompany to the Washington office each voucher approved for payment from the reclamation fund. It should not be prepared for transportation requests, bills of lading, or other unpaid liabilities, but the coupons of transportation requests and bills of lading should have indicated thereon to what projects and to what secondary and tertiary accounts they are chargeable.

Transfer sheet.—Whenever charges made against one primary account are to be reentered against other accounts, transfer sheets (Form 9-504) showing the amount of such charges, the subject-matter thereof, and its distribution should be prepared by the office entitled to the credit.

Debit and credit notices.—Appropriate debit and credit notices (Forms 9-505, 9-506) should be prepared in the Washington office and sent to the resident engineers or to the proper engineers in charge, covering all charges and allowances to the project arising from without the office of such engineers.

All vouchers made by the several experts and specialists of the Service for purchases which are to be applied to the various projects should, after approval by the engineers incurring the expense, be sent to the resident engineers for record and should be accompanied by appropriate charge sheets. Such action will avoid discrepancies in the accounts and give the resident engineers fuller information regarding the nature of the expenditure than can be given in other ways.

Vouchers for services and for traveling and field accounts of men under their direction need not be so transmitted, but should be sent on direct for payment. When such men are detailed to a project for any considerable period and are to be paid there, notice of the salary to

[a] The wages of cooks, which are a part of the cost of subsistence; of men in Government employ engaged in repairs, which are a part of the cost of supplies; of janitors, which are a part of the cost of rent; and of hostlers and stablemen, which are a part of the cost of the care of animals, are all to be entered under "Services."

be paid them and of the date from which such payment should be made should be sent to the resident engineer (Form 9–507).

General charges.—Work done in one State for the benefit of the entire Service (as tests of certain methods of doing work or of certain materials) should be charged to appropriate accounts under the head of the Washington office, that the expense thereof may be apportioned to the entire Service, as are all the accounts under Washington.

The general charges for a State having one principal project under construction or about to be entered on should be charged to that project; reconnaissance charges should be placed against definite projects, either those under way or those being considered.

It appears that there will not be need of any account outside of the Washington office other than those for distinct projects, except reconnaissance in those States where no definite project has yet been developed.

Unpaid liabilities.—In the matter of salaries and of the greater portion of its miscellaneous purchases the Government is not a credit purchaser. But in certain lines of business, particularly transportation, where the purchases are large in number and relatively small in amount individually, the charges are allowed to remain on account until such time as a statement of account or "bill" therefor is rendered, when charges, often covering a large number of items, are vouchered and paid. Such charges are mainly for passenger fares, freight, express, and telegraph tolls.

There should be kept in each district or project office a "record of liabilities incurred for which vouchers have not been approved."

Herein should be recorded all transportation requests and bills of lading issued to transportation companies, giving date, number, railroads, etc., affected, points from and to, amount, and accounts chargeable.

When transportation requests and bills of lading are delivered in blank, a record should be made of the number, etc., and a pencil memorandum be made of the date and name of person to whom delivered, until such time as the other information can be supplied.

Charge sheets should not be prepared for such unpaid liabilities until the accounts therefor have been vouchered and approved, nor should entries therefor be made in any of the various ledgers at project, district, or Washington offices, as such entries are to be made only on charge sheets based on paid or approved vouchers.

When notice is received of the approval of the voucher covering an item of this record, the date of approval should be entered in the last column.

All items of this record for which the vouchers have not yet been approved are outstanding liabilities.

COST KEEPING.

Definition.—Cost keeping, or the summation of actual cost of work done, is founded on the expenses incurred, but is largely dependent upon engineering data. It is important to carefully observe the distinction between bookkeeping in general, which consists in keeping the record of expenditures, liabilities, etc., and cost keeping as above defined. There is a wide distinction to be observed between the amount of money which is spent, for example, on a contract for the construction of a canal and the amount which that canal actually costs the contractor. The first is of general interest from the financial standpoint mainly; the second is of most value to the engineers, not only for comparison with the original estimates of cost, but as a guide in the preparation of future estimates.

The keeping of a record of the contract cost is relatively a simple matter. This can be ascertained from the contract itself or record of expenditures. The actual cost of the work is determined, however, with considerable difficulty, since it involves the recording daily of facts concerning number of men employed, material used, and miscellaneous expenditures.

The item of cost keeping is largely an engineering function, and all estimates of the actual or net cost of construction must be made under the supervision of an engineer concerned immediately with the execution of the work. The record books should be simple yet explicit, and the dates noted should be collated and arranged according to some uniform system susceptible of checking and verification.

For the cost accounts three classes of records are necessary—stores books, showing purchases and how the articles are applied to the project and giving inventories of stocks on hand; time books, showing the entire force account of the Government and of contractors; and reports or estimates of quantities of work done. As very different conditions exist during the preliminary period of survey and the later period of construction, two sets of time books and reports are provided, intended, respectively, for use in collecting and reporting the costs of survey and the costs of construction.

Stores accounts.—For stores records ordinary blank books with ledger ruling may be used, with the following instructions inserted in each book (Form 9–508):

All stores should be divided into five general classes corresponding to the subdivisions of the charge sheet relating to stores.

Equipment: All nonexpendable property, including public animals. (See Regulations U. S. G. S., sec. 54, p. 41.)

Materials: All expendable property entering into construction and remaining a part thereof.

Supplies: All expendable property used in preliminary and con-

struction work, and wholly consumed therein, fuel, explosives, lubricants, illumination, repairs (including services when combined with "job" charges for repair supplies), and stationery.

Subsistence: All rations, food, water, etc., for men only. (See Regulations U. S. G. S., 1903, sec. 62, p. 48.)

Forage: All feed for public or hired animals, etc. (See Regulations U. S. G. S., 1903, sec. 45, p. 33, and sec. 64, p. 49.)

For equipment use the property account blanks of the United States Geological Survey, retaining a duplicate and indicating thereon not only the name of the person in possession of the property, but also the feature of the work on which it is then used.

For each of the other divisions of the stores accounts, there should be a separate book or division of the book in which there should be opened an account with each general kind of stores handled. There may be one miscellaneous account in each general class, to which will be entered single purchases for specific purposes, showing how the articles were applied.

The accounts under "Subsistence" should conform to the ration list, and where different articles are grouped under one heading of that list, as fresh meat, which includes fish, poultry, and eggs, the substitute articles should be entered to appropriate accounts following the principal one.

Indicate all debits in number of units, as pounds, gallons, etc.; enter description and whence procured, with voucher number, if possible; show unit price thereon and gross cost.

Indicate all credits in like manner and state the purpose to which the stores are applied; state feature of the work rather than the person to whom delivered.

Balances should always agree with the inventories of stores on hand.

All purchases, whether for the general store or for field parties, and all requisitions for stores made by field parties on the general store should be made on requisition blanks in duplicate (Form 9-509), and one copy be retained by the person ordering, the other, in the case of purchases from outside suppliers, to accompany the invoice rendered for the goods. When stores are furnished by the general stores keeper on such requisitions, an invoice in duplicate (Form 9-510) should be prepared by him for the articles supplied, showing, in case of failure to complete the order, when the other articles will be furnished.

Analyses of costs.—A logical report upon costs requires the following procedure, which should be as nearly uniform as possible in all work of this Service:

(1) The collection of data in the field.

(2) The arrangement and tabulation of these data in the local offices.

(3) The transmission to superior officers of the results of such collation as fully as required to be clearly understood, but not in such detail as to defeat the purposes of the reports by rendering them cumbersome.

Costs of surveys.—For the Government executive and the engineering force in the prosecution of surveys, both during the preliminary stages and the construction periods, the following forms are provided:

(1) Time book (Form 9–511), containing blanks in which to record the names and permanent addresses of members of the parties; a daily time record of men and teams, daily memoranda, and a monthly summary.

(2) Weekly report (Form 9–512) from chiefs of party to resident engineers.

(3) Monthly report (Form 9–513) from chiefs of party and others in charge of specific classes of work to the resident engineers for approval and transmission to the supervising engineers.

(4) Monthly summary (Form 9–514) of operations from resident engineers to superior officers.

All of these forms are based upon the distribution provided for on the charge sheet.

Costs of construction.—For the collection and transmission of information concerning work on construction, whether under contract or on force account, the following forms are provided:

(1) Time book (Form 9–515), similar to the one prepared for use on surveys except that the blanks for daily memoranda and monthly summary are omitted. All engineers or inspectors having relations with contractors or in direct charge of any portions of construction work on force account should keep journals, and should record fully the daily operations, instructions, and information furnished to contractors or foremen and lists of the expenditures made.

(2) Field engineering record (Form 9–516), for use by the assistant engineer in charge of a section of construction work.

(3) Engineering summary (Form 9–517), on which is to be collected the data recorded on the previous form, and a copy of which is to be prepared for the resident and supervising engineers.

(4) Monthly statement (Form 9–518), to be printed on translucent paper. This statement is to be prepared at the same time as the voucher (Form 9–268), and should show all the data on the voucher. Sufficient copies should be prepared to furnish at least one copy each to the offices of the resident, supervising, and chief engineers and one to the contractor.

Cost summary.—For the working out of contractors' prime costs

(i. e., costs of labor, materials, and supplies, and excluding equipment in use and general charges at distant offices "not in sight"), a cost summary or statement of force employed, material delivered, and work done (Form 9-519) is prepared on translucent paper. This is divided into vertical sections, which should be supplied with appropriate headings to indicate the character and class of the excavation, masonry, etc. Under excavation, there should also be reported the kind of earth, the method of excavating employed—whether by machinery or hand labor—the mode of transportation, and the length of haul. Under masonry, if for concrete in place, there should be reported the method of mixing, the proportions and materials used, the mode of transportation, and the length of haul. It is divided horizontally into sections headed "labor," under which should be entered all man or team labor, irrespective of whether teams are owned or hired by the contractor, at the current rates for such service, and "materials and supplies furnished by contractor," under which should be entered all stores furnished by the contractor which have been applied to or consumed upon the work done.

The cost to contractor obtained by a summation of the charges for labor, materials, etc., will be a prime cost, and will not, excepting indirectly, include depreciation of equipment or executive charges.

Below are spaces for the contract price, for "materials and supplies" furnished by the Government, and "engineering expenses," the last two supplied with sufficient blank lines to permit them to be divided into their principal elements, as are the force and material accounts of the contractor above.

A summation of these last three items will furnish a prime cost to the Government, which again does not otherwise than indirectly include depreciation of equipment or State or Washington charges.

Report of costs.—For a concise statement to the chief engineer a report of costs (Form 9-520) is prepared which will present on one sheet of letter size the kind and quantity of work done on each division of the project work and the cost thereof to the contractors. Also the cost to the Government for amounts paid to contractors, for materials and supplies furnished, for engineering expenses, and the total cost to date. The unit costs shown are the contractors' prime cost, the unit price per contract, and the Government prime cost. A statement of the whole number of men employed on contract work and on engineering work is provided for.

PROGRESS DIAGRAMS.

Progress maps or diagrams showing graphically the work accomplished should, whenever practicable, be prepared by engineers in charge of specific work to accompany their reports to the supervising and chief engineers.

Such maps and diagrams must necessarily be drawn specifically for each project, but they should be as nearly uniform in plan and details as possible. It is recommended that, whenever practicable, these diagrams be prepared in the Washington office, under the direction of the resident subcommittee hereinafter referred to, in accordance with data and suggestions furnished by the supervising engineers, the plans to be photographed and as many prints as may be required to be sent to the supervising engineers having jurisdiction. These plans must be simple, so that they may be readily understood at a glance by members of Congress and others not engineers, and must show the character, amount, and locality of the work and the cost thereof.

Whenever it is not practicable for such maps and diagrams to be made in the Washington office, they may be prepared in the office of the project or supervising engineers, but in such cases they should, if possible, be sent at once to Washington for reproduction and return. In all such progress maps and diagrams standard colors showing the work accomplished in each month should be used, sheets of such standard colors being furnished from the Washington office.*

All such maps and diagrams should be of such size that they may be folded to letter size, and in no case should they be larger than 4 times letter size—i. e., 16 by 21 inches.

The maps and diagrams of progress and the reports of cost and other operations should be properly collated and filed in the Washington office, convenient for ready reference. The information to be obtained from such statistics as they are gradually accumulated can then be tabulated and put in such shape as to be available for the benefit of the entire Service.

PREPARATION OF FORMS.

All blanks of the Reclamation Service having relation to accounts and reports, including vouchers, charge sheets, debit and credit notices, bills of lading, property returns, weekly and monthly reports, and circulars of instructions, should be printed on paper of distinctive color.

It is recommended that the preparation and final approval of the forms which are herein proposed and which further experience may show to be essential for the keeping of accounts and reports of progress shall be intrusted to the members of this committee residing in Washington (Messrs. Webster, Olberg, and Paul), but that suggested forms be submitted for suggestion and criticism to the other

* See p. 230.

members of this committee before final action is taken. All such forms should be procured from Washington.

It is recommended that prior to the establishment of further local accounts the Washington office be consulted in order to bring about a uniform system of accounts throughout the Service.

OPERATIONS IN WASHINGTON OFFICE.

In the Washington office the complete books of the Reclamation Service are to be kept in simple yet explicit form, showing resources, liabilities, and expenditures. The charges made and the totals of expenditures are to be sent from time to time to the engineers interested, and the books in the local offices should be kept in accord with those in the Washington office.

OPERATIONS IN LOCAL OFFICES.

In each local office the books should be kept on the same general system as those in the Washington office, but in addition the local office should keep all of the original notebooks and other records which go to show both the original estimates and the cost-keeping records. As nearly as possible a uniform system should be employed in the latter operations, so that assistant engineers accustomed to cost keeping in one locality can on being transferred continue the work at another point.

The committee recommends that duplicate copies of this report, if approved, or of so much of it as may be adopted, be prepared and, with a complete set of the forms referred to, be sent each engineer having charge of local accounts.

REPORT OF COMMITTEE ON DUTY OF WATER, ALKALI, AND DRAINAGE.

The work of the Reclamation Service in the construction of irrigation works of magnitude involves a series of investigations and experiments whose object is to determine the practicability of irrigating certain lands. Such experiments and investigations are an essential part of the work which the Secretary of the Interior is authorized to undertake in section 2 of the reclamation act, and are necessary in order for him to determine "all the facts relative to the practicability of each irrigation project." Among such investigations and experiments are those on the duty of water, soil investigations, experiments upon the reclamation of alkali land, drainage experiments, etc. Each and in some cases all of these should be investigated during the progress of the surveys leading up to the building of a project.

DUTY OF WATER.

The duty of water under a stream should be known before a project is approved, in order that canals can be designed so as to carry the amount of water proper for the irrigation of the farms lying under them. While it is true that the duty will vary with every kind of plant grown under every variety of soil in every climate, and even with the man using the water, yet some average duty should be determined and the canal cross sections and grades based thereon.

The importance of the exact determination of the duty of water can not be overestimated. Where a figure too low is taken, the plants grown will suffer, low yields will result, and the farmers will not receive the full benefit of their labors. On the other hand, where too high a duty is taken, the area of land which can be irrigated by a given water supply is underestimated, valuable land is often left dry, and too much water is used, the farmer thereby not only damaging his own lands and crops but those of his neighbors lower down.

Many observations have been made upon the duty of water in various parts of the United States, and it is proposed that this information be collected and digested for the use of engineers.

There are, however, many districts where little or nothing has been done in this connection, and it becomes necessary to observe irrigated fields in the vicinity to determine this quantity. This has been done in the past and should be encouraged in the future. It is hoped, however, that methods for this work can be made uniform in all districts.

Where markedly different types of soil or methods of farming occur in sufficiently large areas to be irrigated by independent canals, the duty of water should be determined for each type; but where, as is usually the case, the types are intermixed and it is not possible to find large areas of one type of soil or of farming, the piece of ground selected should be nearly an average of the types and should have the crops of the locality in about the same proportion as in the whole district. If it is possible to do so, an arrangement should be made by which the engineer in charge may have some control of the amount of water in the experiment. That is, he should endeavor to determine the best practice rather than that ordinarily followed in the vicinity.

All water used should be measured through a weir, or, in case of muddy waters, through a flume, the records being kept by recording weir gage. The yield of the crops grown under the experiment should be determined.

As a further check upon the duty of water, it is well, where possible, to measure the duty under a large canal if any exist in the com-

munity or near by. A recording gage should be placel at the head of the canal and the area irrigated determined, together with all possible facts regarding the yield and quality of the crops grown.

While the primary object of the work is to determine the capacity of the irrigating canals and the area to be irrigated, and one year's record might be sufficient for this, still, as the actual amount needed for each acre need not be stated until applications for water rights are filed, it is thought well to continue the records for at least five years, so as to overcome discrepancies caused by unusual seasons and to determine as accurately as possible the best practice and to start each district right.

The question of the rate and time of delivery of the water is of especial importance and one which has unfortunately received but little attention. When pumping plants are to be built, it is of prime importance to know the maximum rate of delivery needed, and the same considerations apply to canals.

ALKALI AND DRAINAGE.

The alkali problem is one of vital interest to the irrigation farmer. One-eighth of the land which has been irrigated in the United States has been damaged by alkali to such an extent that its cultivation is no longer profitable. Such a loss is serious, amounting to nearly $50,000,000, and indicates something very unsound in the practice heretofore pursued. Our observations clearly indicate that this loss is largely due to lack of drainage, and the success in adequately drained regions indicates the fact that drainage prevents such loss.

To prevent any loss of land in the projects irrigated by the Service it becomes necessary for some study to be made of the question, and preventives applied.

Experimental work so involved falls under two classes: (1) Methods of preventing damage from alkali, and (2) methods of reclaiming lands already alkaline. It is the sense of this committee that the Service should carry on certain experimental work on the drainage and management of alkali lands. This work might be done by the Department of Agriculture by request from this Service, but the committee recommends, after careful consideration, that it be taken up and entirely carried out by the Reclamation Service.

Investigations in drainage and alkali reclamation work should be carried on on tracts of 10 or 20 acres. Where possible the land should be in private ownership, and the Service should arrange with the owner to do all necessary farm work, and possibly to pay for the material used, as he can not well benefit thereby. Where such an

arrangement is not possible, a tract should be reserved from entry for use in these investigations (see sec. 7, reclamation act).

Crop introduction.—The introduction of suitable crops for each project becomes the duty of the Service. The majority of farmers in the new projects will be inexperienced, and, in order that they be enabled to return the cost of irrigation, they should be advised regarding the best crops to grow and the best ways of growing and marketing them. Work of this sort involves farming operations and seems to fall within the scope of the Department of Agriculture and the experiment stations.

It is suggested that upon the approval of a project the Secretary of Agriculture be informed of the location, extent, and probable time of completion of the project, and asked to suggest crops and methods of farming adapted to the country.

Farm-unit maps.—The report of the El Paso committee, consisting of Messrs. Savage, Bien, and Means, on farm units is as follows:

The principle on which the dealings with the settler should be based is that he shall pay for what he gets and know for what he pays. Accordingly, he should know the number of acres of irrigable land he receives and the amount of water to be furnished for each acre per annum. It is recommended—

(*a*) That the farm-unit classification sheets shall show in each farm unit the boundary of the irrigable land and the area of irrigable land, in acres.

(*b*) That a water-right application shall state the number of acre-feet per annum to be furnished per acre.

(*c*) That the charge for water rights shall be the same per acre of irrigable land.

(*d*) That the land be classified into two grades—irrigable and nonirrigable—and that all farm units contain the same area of irrigable land as nearly as practicable, except in the case of areas near towns and those susceptible of growing more valuable crops, thus providing for two sizes of irrigable areas in the farm units. The maximum number of acres of irrigable land fixed for each class in a project shall be adhered to as closely as possible.

(*e*) That the charge per acre for water rights on private land be the same as for public land, and that the irrigable area in each tract be determined in the same way as for public land, the irrigable area allowed one man in no case to exceed 160 acres.

RECOMMENDATIONS.

After discussion of the above subjects in committee meetings and in general conference with the engineers, the following specific recommendations were reported for approval:

(1) That the report of the El Paso committee on farm units be adopted and made the rule of the Service.

(2) That determinations of the duty of water be made by engineers in all projects where reliable figures are not at hand. In all such investigations the object shall be to determine the best practice in use of water, the total amount of water per acre per year, and the amount

used each month during the season, with the maximum delivery needed at any one time.

(3) That drainage of all lands to be irrigated be considered in detail, and that drainage ditches be considered an essential part of the irrigation works.

(4) That investigation upon the best methods of reclaiming and managing alkali or other lands is essential to the success of the reclamation work in certain projects.

(5) That the introduction of suitable crops and agricultural industries is important, and engineers in charge of projects are urged to give all possible aid and assistance in investigations leading to the solution of these problems. The details of these investigations are to be worked out as each arises.

REPORT OF COMMITTEE ON ORGANIZATION.

Three meetings of the committee on organization were held, at which a number of engineers, notably Messrs. Ross, Sanders, Fellows, and Storrs, not members of the committee, attended and materially assisted in the discussion.

The committee believes that it is undesirable to establish absolute rules of procedure, as conditions and circumstances may change so as to require other methods.

Chief engineer and assistant chief engineer.—It is especially desirable that the Washington office, and particularly the chief engineer, should keep in close personal touch with conditions in the field.

The committee believes that the present practice of providing for visits to the various projects by the chief engineer and assistant chief engineer, alternately, should be continued for the benefit of the Service and of the executive engineers in the field.

Consulting engineers.—For the protection of the Service the present practice should be continued of having all vital points relative to the policy and construction of the work passed upon by a board of consulting engineers. The success of the chief engineer in securing the services of eminent consulting engineers is cause for congratulation. Consulting engineers should act in an advisory capacity and should not issue instructions in an executive capacity to the men who are the assistants on a project. After consideration of a question, the finding of a majority of the board should constitute a final decision so far as the board is concerned. This report should then be presented to the chief engineer.

Project board meetings.—The district or supervising engineer should, when necessary, request the chief engineer to convene a board of consulting engineers. Because of the intimate knowledge of the

project in question which is had by the executive engineers it is due to them, as well as to the chief engineer, that they should be represented in such conference.

The chief engineer or the assistant chief engineer may, in his discretion, convene a board of consulting engineers to act on any question where consultation is deemed necessary, and the chief engineer and assistant chief engineer may be members of the board when they so desire.

In order that the construction work may be expedited, the decision of the project board should be accepted by the supervising engineer as final, and he should issue instructions in accordance therewith. This action should be presented to the chief engineer for his review. The action of the project board involving the acceptance or rejection of a project should, however, be submitted to the chief engineer for his decision before action is taken by the supervising engineer.

Executive engineers.—In order that the related duties of the various engineers may be clearly defined and the work thus expedited, the supervising or district engineers should be considered as the executive heads and in charge of the management of their respective sections as the representatives of the chief engineer.

The chief engineer should place supervising or district engineers in charge of certain specific territories. Under the district or supervising engineer may be placed project engineers. These executive engineers should prepare and present all data relative to any particular project or section thereof. The constructing engineer should, if possible, prepare plans and specifications, or assist in their preparation, when they relate to work which he is to build.

The positions of district engineer and supervising engineer apparently are not well defined. It would appear advisable to have but one intermediate engineer between the project engineer and the chief engineer, and it is immaterial whether such engineer be called a district or supervising engineer.

The field of the supervising engineer should not be so large that he can not have an intimate, detailed knowledge of all the work being performed within the territory over which he has jurisdiction. His report to the chief engineer should be based on full and personal knowledge.

Construction engineers.—The construction engineer should be definitely assigned to some important construction. He should reside near the work and be responsible for its construction and completion. He should report through the supervising engineer to the chief engineer. The construction engineer should be a member of the board when his work is under discussion. He should be available for consultation work in the immediate vicinity.

Power engineers.—The power engineers appointed by the chief

ngineer should be available as experts on all matters pertaining to he generation and transmission of power and its application to umping, and as such should be freely consulted by the other engi-eers.

The power engineers should be called on by the supervising engi-eer to assist in the preliminary investigations of such projects as ave power possibilities, and in such cases should furnish estimates f first cost and operation of proposed power plants to the supervis-ng engineer and forward a copy to the chief engineer. It would be dvisable for the investigation of apparatus and devices to be left ntirely to the power engineer wherever possible.

After any project is approved for construction the power engineer hould have executive charge of all matters concerning design and onstruction of power plant and pumping system and should issue pecifications, on approval by the project board, for the apparatus eeded; and when bids have been accepted on the principal units he hould prepare designs for the plant as a whole. In a water-power lant the power engineer should be guided by the supervising engi-eer in the laying out of the delivery of the water to and its discharge rom the plant.

All accounts connected with the power and pumping work should e kept with the other accounts on the project, but in such a manner hat the cost can be segregated and be subject to the approval of the upervising engineer.

The engineer of any project and the power engineer should confer ogether in all matters where their work meets, and each on request hould furnish the other any information necessary to the completion f the plan of the project as a whole.

Owing to the peculiar nature of the work of the power engineer, t is essential that his office should have a fixed location or head-uarters. The larger part of the study and design of a power project s made in the office, and that office will require frequent communica-ion with manufacturers or their agents, and should be located with hat in view as centrally as possible in the district the engineer is to over.

The power engineer should have charge of the operation of the ower plants in his district.

The power engineer should be a member of the project board when uestions involving his work are under consideration.

REPORT OF COMMITTEE ON POWER AND PUMPING.

GENERAL STATEMENT.

The applying of transmitted water power to the uses of irrigation, hether to operate large pumps from lakes or streams or to pump ater from underground sources, offers a very wide field for consid-

eration and may be divided into several classes, according to whether the transmission is short or long (it may be extended up to 75 miles and used to distribute power over a large area), and according to whether the pumping is from wells or from streams or canals.

COST OF INSTALLATION AND OPERATION.

Specific example.—The thing which at this time is of the utmost importance to the Service is the probable cost of such installations. Estimates are being worked up on several projects, from which perhaps some idea can be gathered. In one case, where power is derived from water already stored for a canal system, and where only such hydraulic construction as water mains for delivering the water to the water wheels is charged, the cost works out about $25 an acre. The transmission in this case is about 75 miles, covering an extended area; the average lift on the pumping plants is about 50 feet, using centrifugal pumps directly connected to motors; and the pumps are to be run not more than 200 days a year and to be given a rest during such periods as there is rain or an unusual supply of water due to rise of the natural streams supplying the gravity system.

The cost of operation of a plant of this character, this one being laid out for 40,000 acres, will approximate about 40 cents an acre-foot, allowing for depreciation, salaries, wages, and repairs; but if a portion of the care of this system can be merged under the management of the operation of the gravity canals this can be somewhat reduced.

In another case, where the transmission is short and the pumping units are large, and no step-up transformers nor step-down transformers are required, the cost amounts to about $10 an acre, and the operation to about 25 cents per acre-foot. The distance here is within 15 miles and the power derived is an incident of the construction of a diversion dam for a gravity system. These two cases illustrate what may be done along these particular lines.

In general, if a power plant is to be constructed solely and purely for the operation of such a system, the hydraulic work connected with it must not be the greater feature of the cost, for the electrical and mechanical appliances have practically a fixed cost for a given amount of power. The varying costs are the cost of hydraulic development and the cost of the transmission line controlled by its length. It can be very readily seen also that the lift on the pumps cuts a very large figure in all such cases.

A problem similar to the long-distance transmission above has been worked out very well in Water-Supply Paper No. 58, relating to the land around Fresno, and is very similar in cost of installation and operation to the one above mentioned. As a rule, if a high head can be obtained without too great an expenditure for a canal line (by high

head is meant heads above 500 feet), the cost of the hydraulic work does not become, as a rule, excessive.

It can also be shown that in a project where land is lying reasonably level and the water plane is within 2 or 3 feet of the surface and is renewed by floods every year, and where coal or its equivalent has an average value not to exceed $2 a ton, a steam plant can be installed, power transmitted 10 miles either way, and by pumping from wells irrigate as much as 40,000 acres from one plant at an installation cost of about $25 per acre and an operation cost not to exceed $2 per acre per annum, with a water duty of about 3 feet. The above is based on a lift on the pumps not to exceed 30 feet.

CHARACTER OF POWER.

Steam turbines.—There are some localities in which cheap fuel can be obtained where water can be advantageously lifted from streams or canals to heads not exceeding 100 feet by direct-connected apparatus, using steam power. For this purpose the steam turbine, directly connected to a centrifugal pump, offers many advantages, especially if the water to be used in the boilers carries much mineral water, for with the turbine it can all be returned and reduce the cost of cleaning and repairs of boilers.

In some localities where fuel is extremely cheap and the irrigation season short, economy would indicate that the construction of a cheaper class of plant would be best, if other conditions, such as head, etc., would permit, but as a rule the serious question of the price of fuel through long terms of years, beyond the time of those who are planning the construction of these plants, would cause us to be very careful whether or not we build pumping plants to be operated by steam or by any power requiring fuel.

Gas engines.—The gas engine is claiming our consideration in large units to no small degree, but in this country it has not been in operation sufficiently long to warrant extensive recommendations for its use, unless several of the controlling conditions are extremely favorable.

There are now under contract in this country for driving electric generators some large gas-engine units, having a capacity of 5,000 horsepower in a single unit. From the operation of these no doubt sufficient data as to the reliability and economy and the other costs which enter into successful operation may be obtained which will warrant their use for this class of work.

The small gas engine in its many forms and types is undoubtedly one of the best means of obtaining power in units up to as high as 30 horsepower for irrigation work for the individual farmer. In all cases where the power for pumping water for irrigation is to be

derived from the consumption of fuel, used in any form of heat engine, the nature of the crops and the value of the crop per acre per annum will have a great deal to do with the solving of the question of whether they will be used at all or not. But there are some cases where the lift is very light and the water supply plentiful, where undoubtedly they could be applied to crops of a moderate value.

Water turbines.—Another point where we should look for the practical use of pumping plants is in connection with canals across some sections of the country. In building these it is often necessary to overcome a rapid grade by a sudden drop. In numerous cases of that kind there lies, immediately above the canal, land in relatively small areas which could be reached by water elevated to their level by pumping plants. In such cases a simple water wheel of the vertical-shaft turbine type, direct-connected to centrifugal pump mounted on the same housing, submerged in the stream, the water dropping through the turbine wheel, furnishes the power to raise a portion of the water to the high level. In all cases where it is desired to connect the pump and the turbine water wheel together there should be a fall in the canal equal to at least one-quarter of the head against which the water would be lifted.

SUBMISSION TO SPECIAL ENGINEERS.

Wherever a power project is contemplated it would be well that the project engineers, as soon as they are satisfied there is sufficient power and sufficient land to be benefited thereby to make a power plant seem feasible, should put the problem up to those engineers who will eventually become responsible for the design of the power plant.

The nature of the data required will be, first, a diagram of stream flows throughout the year, expressing the flow in second-feet; also a diagram of gage heights, giving the elevation to which the water is to be lifted, and the amounts of water to be pumped each month during the year, showing it by maximums for the month. These data apply to cases where the pump is direct-connected to the water wheel. The other problems are much more complex, and it is well for the engineers interested to have a conference and go over the work together at as early a date as possible.

There have been within the past two years centrifugal pumps designed and placed in operation, working against heads as high as 700 feet, and there may be localities where it will be practical to raise the water for irrigation in large quantities as high as 300 or 400 feet by units direct-connected to water wheels. This type of pump has an efficiency very much higher than the low-lift pumps.

It is desirable in all cases where power is to be used for pumping water that the engineers who are responsible for the power develop-

ment should be consulted as early in the investigations as is practical, and that the responsibility should be placed on them for furnishing the estimates and preliminary plans. Confusion is quite likely to arise should several engineers be working on the same problem, and the best results are likely to be obtained where some individual engineer is responsible for presenting to the chief engineer the estimates which refer to his particular class of work.

WITHDRAWAL OF UNDEVELOPED WATER POWERS.

On some projects which require the diversion and storage of water for irrigation purposes difficulties arise in dealing with private interests, owing to the presence of water-power plants claiming prior rights to the natural flow of the streams from which the water for irrigation purposes must be taken. Water-power plants designed to supply commercial uses require, as a rule, a nearly uniform stream flow throughout the year, whereas irrigation systems require the largest flow during the irrigation season, and, where possible, complete storage of the water during the remainder of the year. For this reason the presence of a water-power plant on a stream whose waters are desired for storage in order to be used for irrigation purposes would necessitate permitting a certain amount of water to pass the storage reservoir in order to supply the water-power plant, thus depriving the irrigation system of that amount.

To avoid complications of the kind above described it is suggested that control of all necessary water powers be secured as early as possible by withdrawing, under the first form, such lands along the streams as will control the situation so far as power development is concerned. It will be much better for the Government to release to private parties those water powers which it is not prepared to utilize itself than to leave them open to be filed on for speculative purposes. When the Government finds it necessary to release to private parties a water power which has been withdrawn, it will be an advantage to be able to make this release under certain conditions as to the use of the water-power privilege, reserving the right to control the natural flow of the stream to such extent as may be necessary to serve the needs of irrigation. It may sometimes happen that the presence of an irrigation storage reservoir on a stream will greatly improve the stream flow for power purposes for commercial plants situated below the reservoir, in which case the power company should pay a part of the expenses of the storage works by which they are benefited.

There are other reasons why the Reclamation Service should secure control over the necessary water powers in the arid regions. For instance, any undeveloped water existing within, say, 100 miles of an

area of land might at some later period be found useful for supplying water by electric transmission for pumping irrigation water for this land. No definite limit can be stated for which power can be economically transmitted, since this is entirely a matter of the relative expense of producing and transmitting the power and the value of the same when applied to beneficial uses. The land on which it is proposed to use the power need not be definitely specified when the withdrawal is requested, but any area that may sometime be reclaimed will serve as the reason for requesting withdrawal.

Another consideration which should not be lost sight of is that some of these water-power possibilities may be found valuable in providing power for construction work on some reclamation projects that will be undertaken later on in this section of the country.

TEMPORARY POWER PLANTS FOR CONSTRUCTION WORK.

The construction of large structures, such as dams and canals, demands the use of large amounts of power, involving the consumption of much fuel, the cost of which is often high on account of the inaccessibility of the work. This power could often be furnished by installing temporary hydraulic or steam plants, where water power or fuel could be cheaply secured, and transmitting electric power for use in the work. Hydraulic power may sometimes be cheaply developed in connection with the diversion of the stream to permit the building of a proposed dam, or at some point on a canal above the point where the storage dam is to be constructed, or on any stream within a radius of a few miles of the proposed construction work. A steam-generating plant may sometimes be warranted to save haulage of fuel over rough mountain roads, the plant being placed at a convenient delivery point on a railroad or at a coal mine. When the construction work is finished the plant can often be sold at nearly full valuation for commercial uses if the Government has no further use for it. If the transmission line can no longer be of use in place, the wire can be sold or shipped to other projects and the pole line will usually be found useful for telephone purposes.

To meet the objection that the Government can not well arrange to put in these temporary power plants, since the actual construction work on the large dams, tunnels, etc., will be done almost entirely by contract, it is suggested: (1) That the temporary plant, after being erected by the Government, might be turned over to the contractors for operation under the supervision of the engineer in charge and under the agreement to maintain the plant in satisfactory working condition to the completion of the work. (2) That the Government retain control and operate the power plant, supplying power to the contractors at a reasonable rate.

If this matter were carefully considered and decided on before the bids were called for, all the prospective bidders could be informed that the Government proposed to install the power plant, thus relieving all bidders of the necessity of determining the cost of producing the power necessary for construction work, which is always an important and very uncertain item in these estimates. Then all bidders could give due weight to the advantage they would derive from having power supplied to them from a power plant constructed by the Government.

In view of the above, the committee recommends that the possibility of furnishing electric power for the construction of large works from temporary steam or hydraulic plants erected by the Government be fully considered by the engineers of the Service prior to drawing specifications and letting contracts for these large structures.

CHARGES FOR PUMPED WATER.

On pumping projects it seems reasonable that the water user should pay for his irrigating water on the basis of the amount of water actually delivered to him. This is unquestionably the proper method to follow on those projects where oil, coal, or other fuel furnishes the power for pumping, since in such cases the operating expenses depend so largely upon the quantity of water pumped. Hence it is proposed that the articles of incorporation for water users' associations, in projects where pumping is to be done by the use of fuel of some sort, include a provision that the annual charge for the cost of maintenance of the works be the same for each share, but that the charge for cost of operation be proportional to the quantity of water actually delivered to each shareholder.

Under this provision a minimum annual payment per share will be made, which will cover the fixed charges and upkeep of the plant. In addition to this, each water user will pay annually for water in proportion to the quantity actually used by him, a price per acre-foot being determined by dividing the total operating expense of the entire system by the total acre-feet of water delivered to all consumers.

One of the strongest arguments in favor of this plan is that it tends to foster economy in the use of water. Another is that the annual payments can be adjusted from year to year to correspond with the varying quantity used, depending upon whether the season is wet or dry.

On pumping projects depending upon water power, the operating expenses will not vary with the quantity pumped to so great an extent as on projects involving the use of fuel for pumping. But in such cases it is a question whether a minimum annual charge for

maintenance and operation should not be made on the basis of the least quantity of water that would under any circumstances be sufficient to irrigate the farm unit, and permit additional water to be purchased by individual users at a certain price per acre-foot. This price per acre-foot would be figured on the actual cost of delivery, and might be different for different parts of the irrigating season. On some projects where water power is utilized for pumping, the power is available throughout the year, but the machinery would usually be idle except during the irrigating season. The system might, however, be operated an additional month or two at merely nominal expense, and where the water and power are available and would otherwise go to waste it would seem desirable to make a very low price for water delivered outside the regular irrigation season in order that the plant and the water might be utilized to the greatest possible extent. Water so applied to land intended for certain crops, such as alfalfa and grain, might greatly lessen the amount of water required during the irrigating season and thus increase the acreage which the pumping plant could serve.

POWER DEVELOPMENT AT DROPS IN MAIN CANALS.

On the main canals of many projects the topography of the country requires an abrupt drop in grade which affords an opportunity for the development of power. It seems certain that this amount of power will not be allowed to go to waste indefinitely, and in most cases will be developed in the course of a comparatively few years. For this reason it would seem advisable in most cases to prepare for the erection of the future power house, when the canal is being constructed, by extending the concrete work, which will usually be required to provide a safe drop for the water from the higher to the lower level, and by constructing the tailrace and foundations for the power house. This additional work can be done at less cost, and with less danger of unequal settlement, if done at the start; otherwise, if the tailrace and foundations for the power plant are built after the canal has been in use for several years, it will be necessary to excavate for the new works in saturated ground, possibly endangering the whole structure, and with some difficulty in securing a perfect bond between the new work and the old. Moreover, this work would have to be done between two irrigating seasons, which would frequently make it necessary to do the work more rapidly than was consistent with economy, and in some locations would necessitate laying concrete in freezing weather.

DUTY OF WATER.

Estimates of probable costs of power and pumping plants necessitate a knowledge of the several factors peculiar to each project—

for instance, of the duty of water, of materials for construction which can be secured locally, of the character of the water to be pumped, and of the ground on which the power and pumping plants are to be built.

In regard to the duty of water, for instance, the essential factor in determining the necessary capacity of the power and pumping plants is the maximum demand for water which will occur during the irrigating season. Since the use of water for irrigation will be prescribed by regulations, it is safe to assume that the maximum demand will not be confined to a single day, but will cover at least a week or ten days. It is suggested that the greatest quantity of water to be used during any ten days of the irrigation season be taken as a maximum by the engineers in determining the capacity of the pumping stations.

Whenever it is possible to provide storage for pumped water, the size of the plant may be materially affected by that fact, since the storage reservoir, even if comparatively small, might serve as an equalizer and enable the system to supply during a period of one or two weeks a much larger quantity of water than the pumping plants alone would be able to deliver in the same length of time.

REPORT OF COMMITTEE ON RECONNAISSANCE AND SURVEYS.

Reconnaissance.—As the development of projects has progressed the imperative necessity for thorough reconnaissance and investigation, conducted along parallel lines as to time of initiation and progress, for every feature of the work, is increasingly manifest, primarily to develop the controlling factors of a project and also their relative and time importance for determination.

In addition to the general and detailed engineering and hydrographic investigations and surveys, many other important matters—some of them possibly controlling—should receive careful consideration early in the investigation of a project.

It is imperative that all branches of the investigation be carried out in a thorough manner and every feature possible to anticipate be given consideration. Investigations of existing records, filings, and statistics, and of available data of any and every kind should be given special attention before initiating field surveys.

It is recognized that the preliminary engineering field investigations should be carried on by men who by natural ability, training, and experience have demonstrated efficiency in this line of work. Detailed instructions should be given them, setting forth the controlling conditions of the reclamation law and other points governing the development of each project to which they are assigned.

Careful consideration should be given to the general project as a business investment for the capital to be involved.

Irrigable lands.—If the area of unpatented lands is nearly sufficient to require the available supply of water, or if a majority of all the available land is unpatented, the situation is much simplified.

In many cases a choice of lands to be irrigated is possible. For example, lands suitable for market gardening located near cities and towns have a much greater value when irrigated than lands located at considerable distance from market, and it is necessary to decide whether water supply shall be developed for lands of comparatively low productive ability located tributary to and near to the source of development, or shall be conducted for long distances to lands which can apparently afford to pay a large price for water supply.

Railway lands.—In the case of railway-grant land it is reasonable to expect that in order to secure the development and settlement of the lands tributary to their lines, with the consequent freight and passenger traffic, the various railway companies will cooperate to the extent of subdividing the lands and offering them for sale under such terms and at such prices as may properly be required in accordance with the reclamation act.

In consideration of the large and perpetual revenue accruing to the transportation companies from the irrigation development, it is expected that a very low selling price per acre will be arranged. It is necessary, however, to have a definite agreement drawn up and properly executed with the railway companies. The attitude of the Reclamation Service toward railroads is a matter for careful consideration, especially where it may be necessary to frequently cross a main trunk line with a main distributing canal. The benefits accruing to the railroad in most cases will be very large, probably $3 or more per acre in annual freight revenue alone, without considering the additional large passenger traffic, which may amount to nearly as much more; and while it seems that they may be expected to cooperate consistently, it is necessary that the Service should have a consistent and uniform basis for dealing with them.

Private lands.—Where private lands, located tributary to the proposed irrigation-supply development, are held in large tracts for investment or otherwise, the owners should be expected and required to enter into agreement and contract guaranteeing to dispose of their holdings over 160 acres, in compliance with the reclamation act, prior to the time when water is to be furnished from the irrigation works.

Borings.—Diamond drill or other borings should be made where required at a timely period in the investigation of a project.

Water users' association.—Where any considerable portion of the irrigable lands under consideration is in the hands of settlers, the atti-

tude of these owners should be definitely determined before undertaking expensive surveys.

Careful attention should be given at the proper time to the organization of a water users' association. Cordial cooperation and every assistance should be given by the Reclamation Service, but undue effort to promote or hasten such an organization is not advisable.

Rights of way.—Investigations of all records should be made at an early time to determine the existence of rights of way for railways, and also to determine ownership of lands required for reservoir purposes, whenever preliminary surveys have determined the necessity for and location of desirable storage sites. The acquisition of right-of-way and flowage rights where reservoir sites have to be obtained is one of considerable importance.

Water rights.—Investigations should, of course, be made to determine the existing water rights. The laws already enacted and in operation in some States provide for the determination and adjudication of water rights. It is expected that other States will soon enact laws for the same purpose.

Before a project can safely be put under construction, or even be finally declared feasible, it is necessary that a complete study of all water rights from the contemplated source of water supply be made, and that an adjudication of such rights be assured.

It has been the policy of the Reclamation Service not to acquire title to the water rights held and used by the private landowners previous to their subscribing their lands and taking irrigation water supply under a reclamation project, but to take over only such portions of existing distribution systems as can be utilized to advantage in connection with the more comprehensive project works, awarding the owners a fair price based on actual cost to reconstruct the ditches or portion of ditches so taken. All the existing private water rights are left intact, with title remaining permanently vested in the present holders to revive automatically and be of full force and effect in the basis of the adjudication previously made, in case circumstances should ever develop requiring their identification and use the same as before reclamation project.

REPORT OF COMMITTEE ON STANDARD PLANS AND SPECIFICATIONS.

STANDARD PLANS.

The general opinion of the engineers assembled at the first conference with this committee was that plans of some of the smaller structures might be standardized. For the present, however, it is recommended that no effort be made to standardize the plans for the larger and more important structures. The territory covered

by the reclamation works extends over more than 20 degrees of longitude, and from the Canadian to the Mexican boundary. In this region a great diversity of soil and climate is found, the elevations varying from 200 feet below to 6,000 or 7,000 feet above the level of the sea. Every structure has a purpose to fulfill, and the design must be influenced more or less by local conditions. The conduit which would answer the conditions in Arizona might be a total failure in Montana. The dam which would successfully hold back the warm waters of the Colorado might be carried off by ice floes in the cold waters of the upper Missouri. A great deal must be left to the judgment of the engineer designing the works, and it may be noted that there is a vast difference in men's ideas. Two engineers might design entirely different structures for the same purpose, and they might both answer that purpose, or they might both be failures. Engineers must be given great latitude in designing of structures, as long as well-recognized scientific principles are observed. No two leaves on any tree or on any number of trees are exactly alike; no two dam sites, no two bridge sites, and no two headworks sites are exactly alike.

Any tendency to standardize the work of the engineer must result in restricting improvements, which are largely a matter of growth, based upon trial and performance in actual practice. Nothing is made perfect at first. The standardizing of our plans must be a matter of growth. Many of the structures which we think are about perfect on paper may upon trial develop weakness which must be provided against in future. We therefore recommend that a beginning be made on the standardization of the smaller structures by selecting from the drawings of the different project engineers now in the Washington office such as appear most suitable for types, and that one of the assistant engineers now in the Washington office be given charge of the work. His duty will be to examine and compare all the drawings now in the office bearing on each structure and design a type of this structure which can be easily modified to suit a particular locality.

STANDARD SPECIFICATIONS.

In the matter of specifications it is recommended that the present "general conditions" be modified so that they will suit the following three contracts:

Contracts for construction work, including canals and all the necessary structures mentioned in the schedule (Form 9-294).

Contracts for machinery and installation (Form 9-294A). This form would apply to all kinds of machinery and manufactured appliances needing special mechanics for installing.

Contracts for furnishing materials only (Form 9-294B). The three amended forms follow.

SPECIFICATIONS FOR CONSTRUCTION (FORM 9-294).

INSTRUCTIONS TO BIDDERS.

1. *Form of proposal and signature.*—The proposal must be made on the form provided for that purpose, inclosed in a sealed envelope, and marked and addressed as required in the notice to bidders. It must state in writing and in figures the unit prices and the sum of money for which the bidder proposes to supply the materials and perform the work called for in the proposal and schedules. If the bid is made by an individual it must be signed with the full name of the bidder, whose address must be given; if it is made by a firm it should be signed with the copartnership name by a member of the firm, and the name and full address of each member should be given; and if it is made by a corporation it should be signed by an officer in the corporate name, and the corporate seal should be attached to such signature. No telegraphic proposal or telegraphic modification of proposal will be considered.

2. *Proposals.*—All blank spaces in the proposal must be filled in, and the phraseology of the proposal shall not be changed and additions shall not be made to the items mentioned therein. Any conditions, limitations, or provisos attached to a proposal will be liable to render it informal and may cause its rejection. Alterations by erasure or interlineation must be explained or noted in the proposal over the signature of the bidder. If a bidder wishes to withdraw his proposal he may do so before the time fixed for the opening, without prejudice to himself, by communicating his purpose in writing to the officer who holds it. No bids received after the time set for opening the proposals will be considered. The right is reserved to reject any or all bids, to accept one part and reject the other, and to waive technical defects, as the interests of the Service may require. Bidders are invited to be present at the opening of proposals.

3. *Certified check.*—Each bidder must submit with his proposal a certified check for the sum stated in the notice to bidders, drawn to the order of the Secretary of the Interior. The proceeds of said check shall become the property of the United States if, for any reason whatever, the bidder withdraws from the competition after the opening of the bids or refuses to execute the required contract and bond if his bid is accepted. Checks will be returned to the unsuccessful bidders after the approval of the contract and bond executed by the successful bidder.

4. *Award.*—The bidder to whom award is made will be required to enter into a written contract with the United States, and to furnish good and approved bond as herein specified, within ten days after receiving such contract for execution. The contract shall be, in its general provisions, in the form adopted by the Reclamation Service, copies of which can be inspected at its offices and will be furnished, if desired, to parties proposing to bid. If the bidder to whom the first award is made fails to enter into a contract as herein provided, the award may be annulled and the contract let to the next most desirable bidder in the opinion of the Secretary of the Interior; and such bidder shall be required to fulfill every stipulation embraced herein as if he were the original party to whom the award was made. A copy of the advertisement and of the general conditions and detail specifications will be attached to and form part of the contract. A corporation to which a contract is awarded will be required,

before the contract is finally executed, to furnish certificate as to its corporate existence and evidence that the officer signing the contract is duly authorized to do so on behalf of the corporation.

5. *Contractor's bond.*—The contractor will be required to give a bond in the sum of 20 per cent of the amount of the contract, unless a different sum is specified in the notice to bidders or proposal, conditioned upon the faithful performance by the contractor of all the covenants, stipulations, and agreements in the contract. If at any time during the continuance of the contract the sureties, or any of them, shall die, or, in the opinion of the Secretary of the Interior, become irresponsible, the Secretary shall have the right to require additional and sufficient sureties, which the contractor shall furnish to the satisfaction of that officer within ten days after notice, and in default thereof the contract may be annulled by the Secretary of the Interior and the work carried to completion in the manner provided in the contract.

6. *Transfers.*—Transfer of a contract, or of any interest therein, is prohibited by law.

GENERAL CONDITIONS.

7. *Eight-hour law, and foreign and convict labor.*—In all construction work eight hours shall constitute a day's work, and no Mongolian labor shall be employed thereon. The importation of foreigners and laborers under contract to perform labor in the United States or the Territories or the District of Columbia is prohibited. (Sec. 3738, Rev. Stat., U. S.; act Aug. 1, 1892, 27 Stat. L., 340; sec. 4, act June 17, 1902, 32 Stat. L., 388; acts Feb. 26, 1885, and Feb. 23, 1887, 23 Stat. L., 332 and 414.) On all construction work the employment of persons undergoing sentences of imprisonment at hard labor which have been imposed by courts of the several States, Territories, or municipalities having criminal jurisdiction is prohibited. (Executive order May 18, 1905.)

8. *Engineer.*—Where the word "engineer" is used in the general conditions or detail specifications, or in the contract, it shall be and is mutually understood to refer to the chief engineer of the Reclamation Service, or any of his authorized assistants or inspectors, limited by the particular duties intrusted to them. The engineer will give the locations and the grades for the work, and no work depending on such locations and grades will be commenced until these have been established. The engineer shall point out to the contractor any neglect or disregard of the plans, specifications, and general conditions of the contract. Upon all questions concerning the execution of the work, the classification of the material in accordance with the specifications, and the determination of costs, the decision of the chief engineer shall be binding on both parties. When two or more contractors are engaged on work in the same vicinity the engineer shall be authorized to direct the manner in which each shall conduct his work so far as it affects other contractors.

9. *Contractor.*—Whenever the word "contractor" is used it shall be held to mean the party, firm, or corporation with whom the contract is made by the United States for the construction of the work, the agent of this party who may be appointed to represent him in the execution of the work, or the legal representatives of the contractor. The foreman in charge of the work will be held to represent the contractor during the absence of the latter or his designated agent.

10. *Foreman and copy of plans, etc.*—The contractor shall at all times keep upon the work a copy of the plans and specifications, so that reference may be made thereto by the engineer, in case of misunderstanding or misconstruction. Instructions given by the engineer to the contractor's foreman or agent on the work shall be considered as having been given to the contractor himself.

11. *Transportation.*—The contractor will afford opportunity to the engineer to obtain copies of the expense bills for transportation charges on all machinery, materials, and supplies shipped to or from the project for use in connection with the work under this contract. On most of the western railroads reduced rates are applicable for the transportation of laborers employed by the contractor traveling in parties of five or more to or from the locality of the work, and allowance should be made therefor in submitting bids; full information concerning these rates can be obtained by application to the engineer in charge of the project.

12. *Local conditions.*—Bidders must satisfy themselves as to the nature of the material and as to all local conditions affecting the work, and no information derived from the maps, plans, specifications, profiles, or drawings, or from the engineer or his assistants, will in any way relieve the contractor from any risks or from fulfilling all the terms of his contract.

13. *Mortgaging of plant, etc.*—The contractor shall not, under any circumstances, give or execute any mortgage, deed of trust, or other conveyance or instrument of any description, affecting or intended to affect his right, title, interest, or property in or to any plant, machinery, tools, appliances, materials, or animals which may at any time be used in the prosecution of this contract.

14. *Damages.*—The contractor will be held responsible for and be required to make good, at his own expense, any and all damages, of whatsoever nature, to persons or property caused by carelessness, neglect, or want of due precaution on the part of the contractor, his agents, employees, or workmen. He will not allow any of his agents, employees, or workmen to trespass upon the premises or lands of persons in the vicinity of the works, and will discharge, at the request of the engineer, anyone in his employ who may be guilty of committing such damage.

15. *Drawings and specification requirements.*—Any drawings or plans which may be listed in the detail specifications shall, together with such detail specifications, be regarded as forming part hereof and of the contract. The engineer will furnish from time to time such detail drawings, plans, profiles, and special specifications as may be necessary to enable the contractor to complete the work in a satisfactory manner. The general conditions and detail specifications shall apply to all work done or material furnished, and shall control the special specifications where the latter are silent. In case of conflict in the general conditions, the detail specifications, and the special specifications the last shall control in the particular work to which they apply.

16. *Experience.*—Bidders must, if required, present satisfactory evidence that they have been regularly engaged in the business of constructing such work as they propose to execute, and that they are fully prepared with the necessary capital, machinery, and material to begin the work promptly and to conduct it to the satisfaction of the Department.

17. *Character of workmen.*—The contractor shall discharge from his service, when required by the engineer, any disorderly, dangerous, insubordinate, or incompetent person employed on or in the vicinity of the works under construction by the United States. None but skilled foremen or workmen shall be employed on work requiring special qualifications, as tunnels, concrete work, etc.

18. *Methods and appliances.*—The methods and appliances adopted by the contractor must be such as will secure a satisfactory quality of work and will enable him to complete the work in the time agreed upon. If at any time such methods and appliances appear inadequate, the engineer may order the

contractor to improve their character, or increase their efficiency, and the contractor must conform to such order; but the failure of the engineer to order such improvement of methods or increase of efficiency will not relieve the contractor from his obligations to perform good work or finish it in the time agreed upon.

19. *Material and workmanship.*—All materials must be of the specified quality and fully equal to approved samples, when samples are required. All work must be done in a thorough, workmanlike manner by mechanics skilled in their various trades, notwithstanding any omission from the drawings or specifications; and anything mentioned in the specifications and not shown in the drawings, or shown in the drawings and not mentioned in the specifications, must be done as though shown or mentioned in both. All materials furnished and all work done shall be subject to rigid inspection, and if not in accordance with the specifications, in the opinion of the engineer, shall be made to conform thereto. Unsatisfactory material will be rejected and shall be immediately removed from the premises, at the cost of the contractor, if so ordered by the engineer.

20. *Samples.*—The contractor shall submit samples of any or all materials proposed to be used in the work if required to do so by the engineer.

21. *Delays.*—The contractor shall not be entitled to any compensation for delays or hindrances to the work from any cause whatever. Extension of time will be allowed for unavoidable delays, such as may result from causes which, in the opinion of the engineer, approved by the Secretary of the Interior, are undoubtedly beyond the control of the contractor, such as acts of Providence, fortuitous events, or the like. If any delay or hindrance is caused by specific instructions on the part of the Secretary of the Interior or the engineer, or by their failure to provide material sufficient to carry on the work, or to give such instructions as may be necessary for the same, or to provide necessary right of way, then such delay will entitle the contractor to an extension of time equivalent to the time lost by such delay. The engineer must receive from the contractor a written notice of claim for such delay before any extension of time will be allowed. Any extension of time, however, shall not release the sureties from their obligation, which shall remain in full force and effect until the discharge of contract. Any application for an extension of time must be accompanied by the formal consent of the sureties thereto, or other sufficient sureties must be furnished by the contractor. In case the contractor should fail to complete the work in the time agreed upon in the contract, or in such extra time as may have been allowed for delays as herein provided, the engineer shall compute and appraise the direct damages for the loss sustained by the United States on account of further employment of engineers, inspectors, and other employees, including all disbursements on the engineering account, properly chargeable to the work. The amount so appraised and computed is hereby agreed upon as liquidated damages, and shall be deducted from any money due the contractor under his contract, and the contractor and sureties shall be liable for any excess. The decision of the chief engineer as to the appraisal of such damages shall be final and binding on both parties. Any provisions in the detail specifications concerning deduction for delay shall be held as modifying or revoking the provisions herein.

22. *Suspension of contract.*—Should the contractor fail to begin the work within the time required, or fail to begin the delivery of material as provided in the contract, or fail to prosecute the work or delivery in such manner as to insure a full compliance with the contract within the time limit, or should any question arise as to whether or not the contractor is properly carrying out the

provisions of his contract in their true intent and meaning, at any time during the progress of the work, notice thereof in writing shall be served upon him, and upon his neglect or refusal to provide means for a more energetic and satisfactory compliance with the contract within the time specified in such notice, then and in either case the Secretary of the Interior shall have the power to suspend the operation of the contract, and he may take possession of all machinery, tools, appliances, and animals employed on any of the works to be constructed under the contract and of all materials belonging to the contractor delivered on the ground, and may use the same to complete the work, or he may employ other parties to carry the contract to completion, substitute other machinery or materials, purchase the material contracted for in such manner as he may deem proper, or hire such force, and buy such machinery, tools, appliances, materials, and animals at the contractor's expense as may be necessary for the proper conduct of the work and for finishing it in the time agreed upon. Any excess of cost arising therefrom over and above the contract price will be charged against the contractor and his sureties, who shall be liable therefor. The failure to order improvement of methods or increase of force, plant, or efficiencies will not relieve the contractor from his obligation to perform good work or finish in the time agreed upon.

23. *Climatic conditions.*—The engineer may order the contractor to suspend any work that may be damaged by inclemency of the weather or other climatic conditions (as, for example, excessive cold or heat), and due allowance shall be made to the contractor for the time actually lost by him on account of such suspension.

24. *Quantities.*—The quantities given in the proposal are for the purpose of comparing bids, and are approximate only, and no claim shall be made against the United States on account of any excess or deficiency, absolute or relative, in the same.

25. *Changes.*—The Secretary of the Interior reserves the right to make such changes in the specifications of work or material at any time as may be deemed advisable, without notice to the surety or sureties on the bond given to secure compliance with the contract, by adding thereto or deducting therefrom, at the unit prices of the contract, or at such allowances for changes of materials as shall be deemed just and reasonable by the engineer, whose decision shall be binding on both parties. The right to make material changes in the quantities listed in the proposal is an essential part of the contract, and bidders must make their estimates accordingly. Should any change be made in a particular piece of work after it has been commenced, so that the contractor is put to extra expense, the engineer shall make reasonable allowance therefor, which action shall be binding on both parties. Extra work or material will be paid for as hereinafter provided.

26. *Extra work or material.*—Extra work or material of a character not provided for in the specifications, if ordered in writing by the engineer, will be paid for at actual necessary cost, as determined by the engineer, plus 15 per cent for profit, superintendence, and general expenses. The cost of extra work shall include all materials, labor, and fuel furnished by the contractor, but shall not include use of tools or machinery, office expenses, general superintendence, or other general expenses. Demand for payment must be made in writing by the contractor promptly upon the completion of the extra work or furnishing of the extra material. The account including the same must be accompanied by the certificate of the engineer that such work has been satisfactorily performed or the material furnished, stating the amount to be allowed therefor.

27. *Structural difficulties.*—Should structural difficulties prevent the execu-

tion of the work as described in the plans and specifications, necessary devi tions therefrom may be permitted by the engineer, but must be withou additional cost to the United States.

28. *Inspection of work.*—The engineers and inspectors appointed by the Secre tary of the Interior shall at all times have the right to inspect the work and mat rials. The contractor shall furnish such persons reasonable facilities for obtain ing such information as they desire respecting the progress and manner of th work and the character of the material, including all information necessary t determine the cost of the work, such as the number of men employed, their pa the time during which they worked on the various classes of construction, et He shall, when required, furnish the engineer and his assistants meals an camp accommodations at reasonable prices at any camp under his contro Whenever the contractor shall be permitted or directed to perform night wor or to vary the period during which work is carried on each day, he shall giv due notice to the engineer so that proper inspection may be provided for. Suc work shall be done under regulations to be furnished in writing by the enginee and no extra compensation shall be allowed therefor.

29. *Removal of defective work.*—The contractor shall remove and rebuild, a his own expense, any part of the work which has been improperly executed, eve though such work should have been already allowed for in the monthly est mates. The engineer shall give to the contractor written notice of such defectiv work when found. If the contractor refuses or neglects to replace such defectiv work, it may be replaced by the United States at the contractor's expense.

30. *Protection of finished work and cleaning up.*—The contractor will be hel responsible for any material furnished to him, and for the care of any finishe work until final completion of the work, and will be required to make good, a his own cost, any damage or injury it may sustain from any cause. He shall take all risks from floods and casualties of every description and make no charg for detention from such causes. He may, however, be allowed a reasonable extension of time on account of such detention, as provided herein. The contractor shall remove all rubbish and unused material upon completion of the work, and place the premises in a condition satisfactory to the engineer.

31. *Errors and omissions.*—The contractor will not be allowed to take advantage of any error or omission in these specifications, as full instructions will always be given should such error or omission be discovered.

32. *Roads and fences.*—All roads crossing the work and subject to interference therefrom must be kept open until proper bridges or crossings are provided, if necessary, and all fences crossing the work must be kept up by the contractor until the work is finished.

33. *Bench marks, stakes, etc.*—All bench marks, witness and side-slope stakes must be carefully preserved by the contractor, and in case of their destruction or removal by him or any of his employees such stakes shall be replaced by the engineer at the contractor's expense.

34. *Right of way.*—The right of way for the works to be constructed and for all necessary borrow pits, channels, spoil banks, ditches, roads, etc., will be provided by the United States.

35. *Sanitation.*—The chief engineer may establish rules for sanitation and police regulations for all forces employed under this contract; and should the contractor fail to enforce these rules, the engineer may enforce them and assess against the contractor the cost thereof, which will be deducted from any sum due on the contract.

36. *Use of liquor.*—The use and sale of intoxicating liquor will be absolutely prohibited on the work except under the direction and supervision of the engineer or his agent, and then only for medicinal purposes.

37. *Claims for work and material.*—The contractor shall promptly make payments to all persons supplying labor and materials in the prosecution of the work, and a condition to this effect shall be incorporated in the bond to be given by the contractor, in pursuance of the act of Congress approved August 13, 1894 (28 Stat. L., 278), and acts amendatory thereof.

38. *Payments.*—The payments due shall be made to the contractor upon the presentation of proper accounts, prepared by the engineer and approved by the chief engineer, in accordance with the provisions made therefor and pertaining to the contract. When the work has been completed or all the material has been delivered, to the satisfaction of the chief engineer, and when a release of all claims against the United States on account of the contract shall have been executed by the contractor, final payment of the balance due will be made.

SPECIFICATIONS FOR MACHINERY AND INSTALLATION (FORM 9-294A).

INSTRUCTIONS TO BIDDERS.

1. *Form of proposal and signature.*—The proposal must be made on the form provided for that purpose, inclosed in a sealed envelope, and marked and addressed as required in the notice to bidders. It must state in writing and in figures the unit prices and the sum of money for which the bidder proposes to supply the materials and perform the work called for in the proposal and schedule. If the bid is made by an individual, it must be signed with the full name of the bidder, whose address must be given; if it is made by a firm, it should be signed with the copartnership name by a member of the firm, and the name and full address of each member should be given; and if it is made by a corporation, it should be signed by an officer, in the corporate name, and the corporate seal should be attached to such signature. No telegraphic proposal or telegraphic modification of proposal will be considered.

2. *Proposals.*—All blank spaces in the proposal must be filled in and the phraseology of the proposal shall not be changed and additions shall not be made to the items mentioned therein. Any conditions, limitations, or provisos attached to a proposal will be liable to render it informal and may cause its rejection. Alterations by erasure or interlineations must be explained or noted in the proposal over the signature of the bidder. If a bidder wishes to withdraw his proposal, he may do so before the time fixed for the opening, without prejudice to himself, by communicating his purpose in writing to the officer who holds it. No bids received after the time set for opening the proposals will be considered. The right is reserved to reject any or all bids, to accept one part and to reject the other, and to waive technical defects, as the interest of the Service may require. Bidders are invited to be present at the opening of proposals.

3. *Certified check.*—Each bidder must submit with his proposal a certified check for the sum stated in the notice to bidders, drawn to the order of the Secretary of the Interior. The proceeds of said checks shall become the property of the United States if, for any reason whatever, the bidder withdraws from the competition after the opening of the bids or refuses to execute the required contract and bond if his bid is accepted. Checks will be returned to the unsuccessful bidders after the approval of the contract and bond executed by the successful bidder.

4. *Award.*—The bidder to whom award is made will be required to enter into a written contract with the United States and to furnish good and approved bond, as herein specified, within ten days after receiving such contract for

execution. The contract shall be, in its general provisions, in the form adopted by the Reclamation Service, copies of which can be inspected at its offices, and will be furnished, if desired, to parties proposing to bid. If the bidder to whom the first award is made fails to enter into a contract as herein provided, the award may be annulled and the contract let to the next most desirable bidder in the opinion of the Secretary of the Interior; and such bidder shall be required to fulfill every stipulation embraced herein as if he were the original party to whom the award was made. A copy of the advertisement and of the general conditions and detail specifications will be attached to and form part of the contract. A corporation to which a contract is awarded will be required, before the contract is finally executed, to furnish certificate as to its corporate existence and evidence that the officer signing the contract is duly authorized to do so on behalf of the corporation.

5. *Contractor's bond.*—The contractor will be required to give a bond in the sum of 20 per cent of the amount of the contract, unless a different sum is specified in the notice to bidders or proposal, conditioned upon the faithful performance by the contractor of all the covenants, stipulations, and agreements in the contract. If at any time during the continuance of the contract the sureties, or any of them, shall die, or, in the opinion of the Secretary of the Interior, become irresponsible, the Secretary shall have the right to require additional and sufficient sureties, which the contractor shall furnish to the satisfaction of that officer within ten days after notice, and in default thereof the contract may be annulled by the Secretary of the Interior and the work carried to completion in the manner provided in the contract.

6. *Transfers.*—Transfer of a contract, or of any interest therein, is prohibited by law.

GENERAL CONDITIONS.

7. *Eight-hour law, and foreign and convict labor.*—In all construction work eight hours shall constitute a day's work, and no Mongolian labor shall be employed thereon. The importation of foreigners and laborers under contract to perform labor in the United States or the Territories or the District of Columbia is prohibited. (Sec. 3738, Rev. Stat., U. S.; act Aug. 1, 1892, 27 Stat. L., 340; sec. 4, act June 17, 1902, 32 Stat. L., 388; acts Feb. 26, 1885, and Feb. 23, 1887, 23 Stat. L., 332 and 414.) On all construction work the employment of persons undergoing sentences of imprisonment at hard labor which have been imposed by courts of the several States, Territories, or municipalities having criminal jurisdiction is prohibited. (Executive order May 18, 1905.)

8. *Engineer.*—Where the word "engineer" is used in the general conditions or detail specifications, or in the contract, it shall be and is mutually understood to refer to the chief engineer of the Reclamation Service or any of his authorized assistants or inspectors, limited by the particular duties intrusted to them. The engineer shall point out to the contractor any neglect or disregard of the plans, specifications, and general conditions of the contract. Upon all questions concerning the execution of the work in accordance with the specifications, and the determination of costs, the decision of the chief engineer shall be binding on both parties. When two or more contractors are engaged on work in the same vicinity the engineer shall be authorized to direct the manner in which each shall conduct his work so far as it affects other contractors.

9. *Contractor.*—Whenever the word "contractor" is used it shall be held to mean the party, firm, or corporation with whom the contract is made by the United States, the agent of this party who may be appointed to represent him in the execution of the work, or the legal representatives of the contractor.

The foreman in charge of the work will be held to represent the contractor during the absence of the latter or his designated agent.

10. *Foreman and copy of plans, etc.*—The contractor shall at all times keep upon the work a copy of the plans and specifications, so that reference may be made thereto by the engineer in case of misunderstanding or misconstruction. Instructions given by the engineer to the contractor's foreman or agent on the work shall be considered as having been given to the contractor himself.

11. *Transportation.*—The contractor will afford opportunity to the engineer to obtain copies of the expense bills for transportation charges on all machinery, materials, and supplies shipped to or from the project for use in connection with the work under this contract. On most of the western railroads reduced rates are applicable for the transportation of laborers employed by the contactor, traveling in parties of five or more to or from the locality of the work, and allowance should be made therefor in submitting bids. Full information concerning these rates can be obtained by application to the engineer in charge of the project.

12. *Local conditions.*—Bidders must satisfy themselves as to the nature of the material and as to all local conditions affecting the work, and no information derived from the maps, plans, specifications, profiles, or drawings, or from the engineer or his assistants, will in any way relieve the contractor from any risks or from fulfilling all the terms of his contract.

13. *Damages.*—The contractor will be held responsible for and be required to make good, at his own expense, any and all damages, of whatsoever nature, to persons or property caused by carelessness, neglect, or want of due precaution on the part of the contractor, his agents, employees, or workmen. He will not allow any of his agents, employees, or workmen to trespass upon the premises or lands of persons in the vicinity of the works, and will discharge, at the request of the engineer, anyone in his employ who may be guilty of committing such damage.

14. *Drawings and specification requirements.*—Any drawings or plans which may be listed in the detail specifications shall, together with such detail specifications, be regarded as forming part hereof and of the contract. The engineer will furnish from time to time such detail drawings, plans, profiles, and special specificatfons as may be necessary to enable the contractor to complete the work in a satisfactory manner. The general conditions and detail specifications shall apply to all work done or material furnished, and shall control the special specifications where the latter are silent. In case of conflict in the general conditions, the detail specifications, and the special specifications, the last shall control in the particular work to which they apply.

15. *Experience.*—Bidders must, if required, present satisfactory evidence that they have been regularly engaged in the business of constructing such work as they propose to execute, and that they are fully prepared with the necessary capital, machinery, and material to begin the work promptly and to conduct it to the satisfaction of the Department.

16. *Character of workmen.*—The contractor shall discharge from his service, when required by the engineer, any disorderly, dangerous, insubordinate, or incompetent person employed on or in the vicinity of the works under construction by the United States. None but skilled foremen or workmen shall be employed on work requiring special qualifications.

17. *Methods and appliances.*—The methods and appliances adopted by the contractor must be such as will secure a satisfactory quality of work and will enable him to complete the work in the time agreed upon. If at any time such methods and appliances appear inadequate, the engineer may order the con-

execution. The contract shall be, in its general provisions, in the form adopted by the Reclamation Service, copies of which can be inspected at its offices, and will be furnished, if desired, to parties proposing to bid. If the bidder to whom the first award is made fails to enter into a contract as herein provided, the award may be annulled and the contract let to the next most desirable bidder in the opinion of the Secretary of the Interior; and such bidder shall be required to fulfill every stipulation embraced herein as if he were the original party to whom the award was made. A copy of the advertisement and of the general conditions and detail specifications will be attached to and form part of the contract. A corporation to which a contract is awarded will be required, before the contract is finally executed, to furnish certificate as to its corporate existence and evidence that the officer signing the contract is duly authorized to do so on behalf of the corporation.

5. *Contractor's bond.*—The contractor will be required to give a bond in the sum of 20 per cent of the amount of the contract, unless a different sum is specified in the notice to bidders or proposal, conditioned upon the faithful performance by the contractor of all the covenants, stipulations, and agreements in the contract. If at any time during the continuance of the contract the sureties, or any of them, shall die, or, in the opinion of the Secretary of the Interior, become irresponsible, the Secretary shall have the right to require additional and sufficient sureties, which the contractor shall furnish to the satisfaction of that officer within ten days after notice, and in default thereof the contract may be annulled by the Secretary of the Interior and the work carried to completion in the manner provided in the contract.

6. *Transfers.*—Transfer of a contract, or of any interest therein, is prohibited by law.

GENERAL CONDITIONS.

7. *Eight-hour law, and foreign and convict labor.*—In all construction work eight hours shall constitute a day's work, and no Mongolian labor shall be employed thereon. The importation of foreigners and laborers under contract to perform labor in the United States or the Territories or the District of Columbia is prohibited. (Sec. 3738, Rev. Stat., U. S.; act Aug. 1, 1892, 27 Stat. L., 340; sec. 4, act June 17, 1902, 32 Stat. L., 388; acts Feb. 26, 1885, and Feb. 23, 1887, 23 Stat. L., 332 and 414.) On all construction work the employment of persons undergoing sentences of imprisonment at hard labor which have been imposed by courts of the several States, Territories, or municipalities having criminal jurisdiction is prohibited. (Executive order May 18, 1905.)

8. *Engineer.*—Where the word "engineer" is used in the general conditions or detail specifications, or in the contract, it shall be and is mutually understood to refer to the chief engineer of the Reclamation Service or any of his authorized assistants or inspectors, limited by the particular duties intrusted to them. The engineer shall point out to the contractor any neglect or disregard of the plans, specifications, and general conditions of the contract. Upon all questions concerning the execution of the work in accordance with the specifications, and the determination of costs, the decision of the chief engineer shall be binding on both parties. When two or more contractors are engaged on work in the same vicinity the engineer shall be authorized to direct the manner in which each shall conduct his work so far as it affects other contractors.

9. *Contractor.*—Whenever the word "contractor" is used it shall be held to mean the party, firm, or corporation with whom the contract is made by the United States, the agent of this party who may be appointed to represent him in the execution of the work, or the legal representatives of the contractor.

The foreman in charge of the work will be held to represent the contractor during the absence of the latter or his designated agent.

10. *Foreman and copy of plans, etc.*—The contractor shall at all times keep upon the work a copy of the plans and specifications, so that reference may be made thereto by the engineer in case of misunderstanding or misconstruction. Instructions given by the engineer to the contractor's foreman or agent on the work shall be considered as having been given to the contractor himself.

11. *Transportation.*—The contractor will afford opportunity to the engineer to obtain copies of the expense bills for transportation charges on all machinery, materials, and supplies shipped to or from the project for use in connection with the work under this contract. On most of the western railroads reduced rates are applicable for the transportation of laborers employed by the contactor, traveling in parties of five or more to or from the locality of the work, and allowance should be made therefor in submitting bids. Full information concerning these rates can be obtained by application to the engineer in charge of the project.

12. *Local conditions.*—Bidders must satisfy themselves as to the nature of the material and as to all local conditions affecting the work, and no information derived from the maps, plans, specifications, profiles, or drawings, or from the engineer or his assistants, will in any way relieve the contractor from any risks or from fulfilling all the terms of his contract.

13. *Damages.*—The contractor will be held responsible for and be required to make good, at his own expense, any and all damages, of whatsoever nature, to persons or property caused by carelessness, neglect, or want of due precaution on the part of the contractor, his agents, employees, or workmen. He will not allow any of his agents, employees, or workmen to trespass upon the premises or lands of persons in the vicinity of the works, and will discharge, at the request of the engineer, anyone in his employ who may be guilty of committing such damage.

14. *Drawings and specification requirements.*—Any drawings or plans which may be listed in the detail specifications shall, together with such detail specifications, be regarded as forming part hereof and of the contract. The engineer will furnish from time to time such detail drawings, plans, profiles, and special specificatfons as may be necessary to enable the contractor to complete the work in a satisfactory manner. The general conditions and detail specifications shall apply to all work done or material furnished, and shall control the special specifications where the latter are silent. In case of conflict in the general conditions, the detail specifications, and the special specifications, the last shall control in the particular work to which they apply.

15. *Experience.*—Bidders must, if required, present satisfactory evidence that they have been regularly engaged in the business of constructing such work as they propose to execute, and that they are fully prepared with the necessary capital, machinery, and material to begin the work promptly and to conduct it to the satisfaction of the Department.

16. *Character of workmen.*—The contractor shall discharge from his service, when required by the engineer, any disorderly, dangerous, insubordinate, or incompetent person employed on or in the vicinity of the works under construction by the United States. None but skilled foremen or workmen shall be employed on work requiring special qualifications.

17. *Methods and appliances.*—The methods and appliances adopted by the contractor must be such as will secure a satisfactory quality of work and will enable him to complete the work in the time agreed upon. If at any time such methods and appliances appear inadequate, the engineer may order the con-

tractor to improve their character or increase their efficiency, and the contract must conform to such order; but the failure of the engineer to order su improvement of methods or increase of efficiency will not relieve the contract from his obligations to perform good work or finish it in the time agreed upo

18. *Material and workmanship.*—All materials must be of the specified qua ity and fully equal to approved samples, when samples are required. All wo must be done in a thorough, workmanlike manner by mechanics skilled in the various trades, notwithstanding any omission from the drawings or specific tions; and anything mentioned in the specifications and not shown in the dra ings, or shown in the drawings and not mentioned in the specifications, mu be done as though shown or mentioned in both. All materials furnished a all work done shall be subject to rigid inspection, and if not in accordan with the specifications, in the opinion of the engineer, shall be made to confor thereto. Unsatisfactory material will be rejected and shall be immediate removed from the premises, at the cost of the contractor, if so ordered by t engineer.

19. *Samples.*—The contractor shall submit samples of any or all materia proposed to be used in the work if required to do so by the engineer.

20. *Delays.*—The contractor shall not be entitled to any compensation f delays or hindrances to the work from any cause whatever. Extension of tin will be allowed for unavoidable delays, such as may result from causes whic in the opinion of the engineer, approved by the Secretary of the Interior, a undoubtedly beyond the control of the contractor, such as acts of Providenc fortuitous events, or the like. If any delay or hindrance is caused by specif instructions on the part of the Secretary of the Interior or the engineer, or b their failure to give such instructions as may be necessary, then such delay wi entitle the contractor to an extension of time equivalent to the time lost by suc delay. The engineer must receive from the contractor a written notice of clai for such delay before any extension of time will be allowed. Any extension o time, however, shall not release the sureties from their obligation, which sha remain in full force and effect until the discharge of contract. Any applicatio for an extension of time must be accompanied by the formal consent of th sureties thereto, or other sufficient sureties must be furnished by the contracto In case the contractor should fail to complete the work in the time agreed upon i the contract, or in such extra time as may have been allowed for delays as herei provided, the engineer shall compute and appraise the direct damages for the los sustained by the United States on account of further employment of engineer inspectors, and other employees, including all disbursements on the engineerin account properly chargeable to the work. The amount so appraised and com puted is hereby agreed upon as liquidated damages, and shall be deducted fro any money due the contractor under his contract, and the contractor and sure ties shall be liable for any excess. The decision of the chief engineer as to th appraisal of such damages shall be final and binding on both parties. Any pr visions in the detail specifications concerning deduction for delay shall be hel as modifying or revoking the provisions herein.

21. *Suspension of contract.*—Should the contractor fail to begin the wor within the time required, or fail to begin the delivery of material as provide in the contract, or fail to prosecute the work or delivery in such manner as t insure a full compliance with the contract within the time limit, or should an question arise as to whether or not the contractor is properly carrying out th provisions of his contract in their true intent and meaning, at any time durin the progress of the work, notice thereof in writing shall be served upon hin and upon his neglect or refusal to provide means for a more energetic and sati factory compliance with the contract within the time specified in such notic

then and in either case the Secretary of the Interior shall have the power to suspend the operation of the contract, and he may take possession of all machinery, tools, appliances, and animals employed on any of the works to be constructed under the contract, and of all materials belonging to the contractor delivered on the ground, and may use the same to complete the work, or he may employ other parties to carry the contract to completion, substitute other machinery or materials, purchase the material contracted for in such manner as he may deem proper, or hire such force and buy such machinery, tools, appliances, materials, and animals at the contractor's expense as may be necessary for the proper conduct of the work and for finishing it in the time agreed upon. Any excess of cost arising therefrom over and above the contract price will be charged against the contractor and his sureties, who shall be liable therefor. The failure to order improvement of methods or increase of force, plant, or efficiencies will not relieve the contractor from his obligation to perform good work or finish in the time agreed upon.

22. *Climatic conditions.*—The engineer may order the contractor to suspend any work that may be damaged by inclemency of the weather or other climatic conditions (as, for example, excessive cold or heat), and due allowance shall be made to the contractor for the time actually lost by him on account of such suspension.

23. *Changes.*—The Secretary of the Interior reserves the right to make such changes in the specifications of work or material at any time as may be deemed advisable, without notice to the surety or sureties on the bond given to secure compliance with the contract, by adding thereto or deducting therefrom, at the unit prices of the contract, or at such allowances for changes of materials as shall be deemed just and reasonable by the engineer, whose decision shall be binding on both parties. The right to make material changes in the quantities listed in the proposal is an essential part of the contract, and bidders must make their estimates accordingly. Should any change be made in a particular piece of work after it has been commenced, so that the contractor is put to extra expense, the engineer shall make reasonable allowance therefor, which action shall be binding on both parties. Extra work or material will be paid for as hereinafter provided.

24. *Extra work or material.*—Extra work or material of a character not provided for in the specifications, if ordered in writing by the engineer, will be paid for at actual necessary cost, as determined by the engineer, plus 15 per cent for profit, superintendence, and general expenses. The cost of extra work shall include all materials, labor, and fuel furnished by the contractor, but shall not include use of tools or machinery, office expenses, general superintendence, or other general expenses. Demand for payment must be made in writing by the contractor promptly upon the completion of the extra work or furnishing of the extra material. The account including the same must be accompanied by the certificate of the engineer that such work has been satisfactorily performed or the material furnished, stating the amount to be allowed therefor.

25. *Structural difficulties.*—Should structural difficulties prevent the execution of the work as described in the plans and specifications, necessary deviations therefrom may be permitted by the engineer, but must be without additional cost to the United States.

26. *Inspection of work.*—The engineers and inspectors appointed by the Secretary of the Interior shall at all times have the right to inspect the work and materials. The contractor shall furnish such persons reasonable facilities for obtaining such information as they desire respecting the progress and manner of the work and the character of the material, including all information necessary to determine the cost of the work, such as the number of men employed,

and sufficient sureties, which the contractor shall furnish to the satisfaction that officer within ten days after notice, and in default thereof the contra may be annulled by the Secretary of the Interior and the work carried to co pletion in the manner provided in the contract.

6. *Transfers.*—Transfer of a contract, or of any interest therein, is prohibit by law.

GENERAL CONDITIONS.

7. *Eight-hour law, and foreign and convict labor.*—In all construction wo eight hours shall constitute a day's work, and no Mongolian labor shall employed thereon. The importation of foreigners and laborers under contra to perform labor in the United States or Territories or the District of Columb is prohibited. (Sec. 3738, Rev. Stat., U. S.; act of Aug. 1, 1892, 27 Stat. L., 34 sec. 4, act June 17, 1902, 32 Stat. L., 388; acts Feb. 26, 1885, and Feb. 23, 18 23 Stat. L., 332 and 414.) On all construction work the employment of perso undergoing sentences of imprisonment at hard labor which have been impos by courts of the several States, Territories, or municipalities having crimin jurisdiction is prohibited. (Executive order May 18, 1905.)

8. *Engineer.*—Where the word "engineer" is used in the general conditio or detail specifications, or in the contract, it shall be and is mutually understo to refer to the chief engineer of the Reclamation Service, or any of his autho ized assistants or inspectors, limited by the particular duties intrusted to the The engineer shall point out to the contractor any neglect or disregard of t specifications and general conditions of the contract.

9. *Contractor.*—Whenever the word "contractor" is used it shall be held mean the party, firm, or corporation with whom the contract is made by t United States, the agent of this party who may be appointed to represent hi in the execution of the work, or the legal representatives of the contracto The foreman in charge of the work will be held to represent the contractor du ing the absence of the latter or his designated agent.

10. *Expense bills.*—Contractors shall afford opportunity to the engineer t obtain copies of the expense bills for transportation charges on all machinery materials, and supplies shipped to or from the project for use in connectio with the work under this contract.

11. *Damages.*—The contractor will be held responsible for and be require to make good, at his own expense, any and all damages, of whatsoever nature to persons or property caused by carelessness, neglect, or want of due precau tion on the part of the contractor, his agents, employees, or workmen. H will not allow any of his agents, employees, or workmen to trespass upon th premises or lands of persons in the vicinity of the works, and will discharge at the request of the engineer, anyone in his employ who may be guilty o committing such damage.

12. *Specification requirements.*—The general conditions and detail specif cations shall apply to all material furnished, and shall control the specia specifications where the latter are silent. In case of conflict in the general co ditions, the detail specifications, and the special specifications the last sha control in the particular work to which they apply.

13. *Character of workmen.*—The contractor shall discharge from his servic when required by the engineer, any disorderly, dangerous, insubordinate, o incompetent person employed on or in the vicinity of the works under co struction by the United States.

14. *Material.*—All materials must be of the specified quality and fully equa to approved samples, when samples are required. All materials furnished sha

be subject to rigid inspection, and if not in accordance with the specifications, in the opinion of the engineer, shall be made to conform thereto. Unsatisfactory material will be rejected and shall be immediately removed from the premises, at the cost of the contractor, if so ordered by the engineer.

15. *Samples.*—The contractor shall submit samples of any or all materials to be furnished if required to do so by the engineer.

16. *Delays.*—The contractor shall not be entitled to any compensation for delays or hindrances from any cause whatever. Extension of time will be allowed for unavoidable delays, such as may result from causes which, in the opinion of the engineer, approved by the Secretary of the Interior, are undoubtedly beyond the control of the contractor, such as acts of Providence, fortuitous events, or the like. If any delay or hindrance is caused by specific instructions on the part of the Secretary of the Interior or the engineer, or by their failure to give such instructions as may be necessary, then such delay will entitle the contractor to an extension of time equivalent to the time lost by such delay. The engineer must receive from the contractor a written notice of claim for such delay before any extension of time will be allowed. Any extension of time, however, shall not release the sureties from their obligation, which shall remain in full force and effect until the discharge of contract. Any application for an extension of time must be accompanied by the formal consent of the sureties thereto, or other sufficient sureties must be furnished by the contractor. In case the contractor should fail to complete the contract in the time agreed upon, or in such extra time as may have been allowed for delays as herein provided, the engineer shall compute and appraise the direct damages for the loss sustained by the United States on account of further employment of engineers, inspectors, and other employees, including all disbursements on the engineering account, properly chargeable to the contract. The amount so appraised and computed is hereby agreed upon as liquidated damages, and shall be deducted from any money due the contractor under his contract, and the contractor and sureties shall be liable for any excess. The decision of the chief engineer as to the appraisal of such damages shall be final and binding on both parties. Any provisions in the detail specifications concerning deduction for delay shall be held as modifying or revoking the provisions herein.

17. *Suspension of contract.*—Should the contractor fail to begin the delivery of material as provided in the contract, or fail to prosecute the delivery in such manner as to insure a full compliance with the contract within the time limit, or should any question arise as to whether or not the contractor is properly carrying out the provisions of his contract in their true intent and meaning, at any time during the progress of the delivery, notice thereof in writing shall be served upon him, and upon his neglect or refusal to provide means for a more energetic and satisfactory compliance with the contract within the time specified in such notice, then and in either case the Secretary of the Interior shall have the power to suspend the operation of the contract, or he may employ other parties to carry the contract to completion, substitute other machinery or materials, or purchase the material contracted for in such manner as he may deem proper. Any excess of cost arising therefrom over and above the contract price will be charged against the contractor and his sureties, who shall be liable therefor.

18. *Inspection.*—The engineers and inspectors appointed by the Secretary of the Interior shall at all times have the right to inspect the materials.

19. *Errors and omissions.*—The contractor will not be allowed to take advantage of any error or omission in these specifications, as full instructions will always be given should such error or omission be discovered.

20. *Claims for work and material.*—The contractor shall promptly make p ments to all persons supplying labor and materials in the prosecution of work, and a condition to this effect shall be incorporated in the bond to given by the contractor, in pursuance of the act of Congress approved Aug 13, 1894 (28 Stat. L., 278), and acts amendatory thereof.

21. *Payments.*—The payments due shall be made to the contractor upon presentation of proper accounts, prepared by the engineer and approved by chief engineer, in accordance with the provisions made therefor and pertain to the contract. When all the material has been delivered, to the satisfact of the chief engineer, and when a release of all claims against the Uni States on account of the contract shall have been executed by the contract final payment of the balance due will be made.

REPORT OF HYDROGRAPHERS ON STREAM MEASUREMENTS.

INTRODUCTION.

The second annual conference of eastern hydrographers was hel in Washington January 3 to 12, inclusive, 1905, in connection wit the conference of the reclamation engineers. It was attended by th men named below:

Hydrographers.—R. E. Horton, M. R. Hall, T. U. Taylor.

Engineers.—H. K. Barrows, A. H. Horton, E. Johnson, jr., John C. Hoyt, E. Murphy, N. C. Grover.

Assistant engineers.—S. K. Clapp, F. W. Hanna, Robert Follansbee, F. Pressey, J. M. Giles, W. G. Steward, C. C. Covert, R. E. Bolster, G. H. Bliss.

Engineering aids.—W. E. Hall, H. L. Eames, F. H. Harley, H. M. Morse, H. Comstock.

The following subjects were discussed:

Winter records for current-meter gaging stations.
Gages.
The maintenance of permanent river stations.
Effect of grass on stream gagings.
Curves of mean velocity and of area.
Secondary or "bench-mark" stations.
Limits of accuracy in reporting discharge measurements in constructing rati tables and in applying gage heights.
Methods of counting seconds and revolutions in making low-water measu ments.
Bench marks.
Equipment for cable stations.
Cost of stream gaging.
The study of data by local men.
The work of the computing section.
Evaporation.
Hydrographic gazetteer.

During one session of the conference Dr. H. C. Frankenfield, of th Weather Bureau, explained the river work carried on under h direction.

RECOMMENDATIONS.

As a result of the discussion the conference made the following recommendations:

Watch for use in stream gaging.—It is recommended that an effort be made to obtain a watch having a second dial of the full size of the watch face and subdivided into 50 parts, the second hand making one complete revolution in 50 seconds, and the advisability of introducing such a timepiece in our work be considered.

Meters and meter ratings.—Inasmuch as the results of our work depend so largely on the meter used, and considering the large cost of the work done with the individual meter compared with the cost of constructing and rating the same, it is the opinion of the conference that too great care in studying these instruments and in maintaining them can not be taken. In this connection the conference has been especially interested in Mr. Steward's ball-bearing meter and in the designs for the rating-station recording device.

It is believed that the meter is capable of giving consistent results at stations where the velocity is less than 0.50 foot per second, which is admitted to be as low as the meters are now rated, with a fair degree of accuracy.

It is therefore recommended that each meter be accurately rated to as low a velocity as the wheel is capable of turning with an even motion. In order that this may be properly done, it is further recommended that steps be taken to construct in the near future at Washington a new meter-rating station, and that it be equipped with Mr. Steward's recording device. It is believed that if possible this station should be so constructed as to be of use both during the summer and winter periods, and that a special channel should be built of sufficient size to serve for this purpose, so that the rating can be made under constant conditions.

The ball-bearing meter, designed by Mr. Steward, will probably be a step toward the improvement of our current-meter work, and it is urged that steps be taken to have constructed for experimental purposes at an early date a meter of this type.

Furthermore, it is believed that a careful study of the behavior of current meters should be made and that they should be rated as they come in from the field, in order to determine the change which has taken place during their use. It is therefore recommended that steps be taken to facilitate the continuance of this work so that the above-mentioned results may be obtained. It is further recommended that an electric meter be constructed that will record 5, 10, or 20 revolutions, for use in making flood measurements.

Annual report.—The general attitude as regards the annual report

on the progress of stream measurements should be one of gre conservatism in publishing estimates. All facts collected dur the year should be published in the annual report for that year.

No estimates of discharge at a station for any unit of time sho be published until sufficient current-meter measurements have b made to cover the ordinary limits of gage heights.

No estimates of discharge, as outlined above, should be publish except in the case of stations with changeable beds.

Until estimates of discharge can be made, as outlined above, data published regarding a gaging station should be substanti as follows:

(*a*) Description of station, bench marks, etc.

(*b*) List of discharge measurements to date.

(*c*) List of daily gage heights for the year.

The general outline for data regarding stations at which rat curves are suitably developed should be substantially as follows the first year:

(*a*) Description of station, bench marks, etc.

(*b*) List of discharge measurements to date.

(*c*) List of daily gage heights for the year.

(*d*) Rating table for station.

(*e*) Daily discharge for the two or more years, where such e mates appear to be desirable.

(*f*) Table of mean monthly discharge, etc., for the two or m years.

After the first year of publishing discharge estimates data fo station shall be substantially as follows:

(*a*) Description of station, bench marks, etc.

(*b*) List of discharge measurements to date.

(*c*) List of daily gage heights for the year.

(*d*) Rating table for station, indicating changes or additions.

(*e*) Daily discharge for the year, where such estimates appear be desirable.

(*f*) Mean monthly discharge, etc., for the year.

It is recognized that there will be exceptional cases where it be inadvisable to adhere closely to the foregoing requirements— example, where temporary stations are maintained for special p poses—and it is intended that the course of procedure in such ca be left to the judgment of the various district hydrographers.

The annual report of progress of stream measurements should h after be published in several volumes, each one of which should devoted to one or more adjacent and complete drainage basins, l as far as possible, divided so as to make the work of each dist

hydrographer in a separate volume or volumes. Each part of the annual report should be published under the name of the hydrographer whose work comprises the greater portion of said part and the name of the party who has charge of the editing and computations in the Washington office.

It is furthermore recommended that arrangements be made whereby parties asking for stream-measurement data shall be supplied, when such requests are made, with the gage heights and discharge measurements to date. Furthermore, that a circular letter be prepared stating that owing to the large amount of work carried on in the hydrographic branch it will be impossible for the office to furnish advance estimates of rating tables and flow.

Maintenance of stations during winter months.—Wherever possible the permanent stations of the Survey should afford continuous records, both winter and summer, and no estimates of discharge should be made for ice-covered streams without discharge measurements made during the ice season.

Especial care should be taken in selecting meter stations to secure sites where as good winter records as possible may be obtained.

The hydrographers may profitably record and report at the end of the present winter certain general facts regarding ice conditions in their territory, so that we may better understand the nature and magnitude of the ice problem. A brief statement should be made for each gaging station, stating—

(*a*) The duration of the ice season.

(*b*) Whether the stream freezes clear across.

(*c*) Whether the ice is persistent, or comes and goes.

(*d*) Whether anchor ice forms; and if so, how it occurs.

(*e*) Whether the ice surface is smooth underneath.

(*f*) Whether winter gage readings are made daily or weekly.

(*g*) What is the maximum ice thickness.

(*h*) Whether it is feasible to measure the discharge through the ice at this station.

(*i*) Whether the water rises to uniform depth in ice.

It is recommended that observers take winter gage readings to water level as it rises in a hole chopped in the ice.

A rubber stamp bearing the words "Report thickness of ice at gage" may be used and a special heading stamped on the regular weekly gage cards for stations where there is but little ice.

Where weekly readings only are required in winter, or, supplementary to the regular cards, a card form as follows may be used:

OBSERVATIONS OF RIVER HEIGHT, ETC., DURING THE FROZ SEASON.

Made on the .....River,

near .....post office, State of .....

Day of week.	Month. 190.....	Day.	Time of day.	Gage height to—		Thickness of ice at gage.
				Water surface.	Top of ice.	

In space below put remarks as to anchor ice, condition of ice, etc.

Mark on the sketch the extent to which the river is frozen, both at the station and above and below the station. Put figures on sketch, showing ice thickness at other places than at gage.

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.....(Sign).....Observer.

UP STREAM.

BANK OF RIVER

DOWN STREAM.

It is recommended that the northern hydrographers make care observations on one or two important rivers the present winter, w special reference to determining:

(*a*) Practical methods of ice measurements.

(*b*) The nature of flow under ice.

(*c*) The vertical velocity curves under ice.

(*d*) The relation between ice flow and free flow at various stages.

(*e*) Whether a constant or any general deductions can be made.

(*f*) The limitations of successful ice measurement.

It is recommended that a committee, consisting of Messrs. Barrov Horton, and Murphy, be appointed and empowered to compile at t end of the present winter season the data above outlined and form late plans for next season's work.

Accuracy of computations.—The following rules relative to acc racy of computations were adopted:

The highest degree of precision consistent with the rational use time and money is imperative.

All items of computation should be expressed by at least 2 and not more than 4 significant figures.

Any measurement in a vertical velocity, mean velocity, or dischar

curve whose per cent of error is 5 times the average per cent error of all the other measurements should be rejected.

In reducing the number of significant figures, or the number of decimal places, by dropping the last figure, the following rules apply:

(*a*) When the figure in the place to be rejected is less than 5, drop it without changing the preceding figure. Example: 1,827.4 becomes 1,827.

(*b*) When the figure in the place to be rejected is greater than 5, drop it and increase the preceding figure by 1. Example: 1,827.6 becomes 1,828.

(*c*) When the figure in the place to be rejected is 5, and it is preceded by an even figure, drop the 5. Example: 1,828.5 becomes 1,828.

(*d*) When the figure in the place to be rejected is 5, and it is preceded by an odd figure, drop the 5 and increase the preceding odd figure by 1. Example: 1,827.5 becomes 1,828.

In constructing and applying rating tables a maximum limit of one-half of 1 per cent error should seldom be exceeded.

REPORT OF COMMITTEE ON WATER LAWS AND FORMS OF WATER USERS' ASSOCIATIONS.

The committee held several sessions with other engineers present, and discussed the subjects within their province at several general sessions. Various phases of the water laws under consideration by the several States were discussed and suggestions made as to the most desirable forms, so far as the operations of the Reclamation Service are concerned.

Among the questions presented were forms of water users' associations and the forms for application for water right under the provisions of the reclamation act.

Amendments to the printed form of articles of incorporation of water users' associations were considered by the committee and discussed in general sessions of the engineers. An amended copy of these articles was submitted to the chief engineer, with the recommendation that a new edition be printed.

The main subject of discussion was the form of water-right application under the provisions of the reclamation act. This discussion was based largely upon the report of a committee, consisting of Messrs. Savage, Bien, and Means, to the conference at El Paso, upon the classification of lands into farm units and the water supply to be furnished.

A form of application for water right was presented to the committee and to the general sessions of the engineers and freely discussed. Copies of two forms of water-right application, drawn so far as possible to meet the views of the engineers present at the con-

ference, are hereto appended, and have been submitted to the Sec tary of the Interior for his approval.

The question of what should be regarded as residence in the neig borhood of the land received special attention at a number of me ings, as well as the method of meeting this condition in the appli tions. As a guide for such limit the distance of 10 miles seemed, the opinion of most of the engineers present, to be a reasona maximum for a country comparatively flat and in which travel easy. For rougher country the distance should be shorter.

The general opinion seems to be that the distance could not specified for all projects, and, accordingly, the forms of applicati have been prepared upon the supposition that the distance for ea project will be specified by the Secretary of the Interior on reco mendation of the chief engineer, and that the applicant shou state the distance of his residence from the land, which would acceptable if within the limit fixed by the Secretary, and if n would be the subject of special consideration in each of such cases.

Among the matters which it would be necessary for each engine to report when his work had progressed to such point that appli tions for water rights should be made are the following: The amou of water to be furnished in acre-feet per annum per acre, measur at the land; the limit of distance of residence which is to be regard as in the neighborhood in the contemplation of the Reclamation A

The amount of water to be furnished per acre per annum can n of course, be fixed for all projects. The general view seemed to that the limit should be fixed for each project. The details concer ing the furnishing of this supply are to be made a matter of regul tion by the Secretary of the Interior, presumably under a few ge eral regulations applicable to all projects, with special regulatio for the separate projects as may be found necessary.

The present situation does not permit of drawing up any regul tions upon this subject, but the experience of the Reclamation Servi in this branch of the work will develop the need of regulations cove ing the various phases of this subject.

FORM A.

Homesteads under the reclamation act.

Application No. ——.
Water right ——. Project ——.

Act of June 17, 1902 (32 Stat., 388).

DEPARTMENT OF THE INTERIOR,
LAND OFFICE AT ——.
——— ——, *190—*.

I, ——— ———, do hereby apply for a water right under the ——— proje subject to the provisions of the act of Congress approved June 17, 1902 (

Stat. L., 388), known as the reclamation act, and the rules and regulations established thereunder; the water supplied in pursuance hereof to be used for the irrigation of and to be appurtenant to ——— acres of irrigable land, as shown on plats on file in this office, approved by the Secretary of the Interior, within the area described as follows:

———————————————————————————————

———————————————————————————————

section ——, township ——, range ——, ——— meridian, an area of ——— acres; the said land having been entered by me under the said reclamation act by homestead application No. —— on the —— day of ———, 190—.

The amount of water to be furnished hereunder shall be ——— acre-feet of water per annum per acre of irrigable land aforesaid, measured at the land; or so much thereof as shall constitute the proportionate share per acre from the water supply actually available for the lands under said project: *Provided*, That the supply furnished shall be limited to the amount of water beneficially used on said irrigable land.

I agree to pay for said water right the sum of $——— per acre for the said area of irrigable land, in ——— annual installments, and to pay promptly when due the annual installments and the maintenance and operating charges duly assessed against said land on account of said water right.

I further agree that upon my failure to comply with the terms of the said reclamation act this application shall be subject to cancellation with the forfeiture of all rights acquired thereunder and of all payments made thereon.

This application must bear the certificate, as hereto attached, of the water users' association under this project, which has entered into contract with the Secretary of the Interior.

If the Secretary of the Interior has made no contract with a water users' association under this project, I agree to file, upon his direction, evidence of membership in the water users' association organized under the said project; in default of which this application shall be subject to cancellation with the forfeiture of all rights acquired thereunder and of all payments made thereon.

And being duly sworn, I further depose and say that I have made no other application, now uncanceled, for a water right under said act of Congress, appurtenant to land now owned or claimed by me except as follows:

Application No. ——, ——— project, ——— of ——— ———, for ———, section ——, township ——, range ——, ——— meridian, an area of ——— acres, and containing ——— acres of irrigable land as determined by the Secretary of the Interior; and that the present application is made in my own behalf and not at the instance or for the benefit of any other person or any association or corporation, either directly or indirectly.

———, *Applicant.*

STATE OF ———, *County of* ———, *ss:*

Subscribed and sworn to before me this —— day of ———, 190—.

My commission expires ——— ——, 190—.

——— ———,

——— ——.

[This affidavit may be sworn to before any officer authorized to administer an oath.]

If the Secretary of the Interior has entered into a contract with a water users' association under the project, the following certificate must be filled out:

——— ———, *190-*

I hereby certify that the applicant for this water right has duly subscr for the stock of this association, for the lands described herein, and tha assessments levied against said stock by this association have been fully up to date.

[CORPORATE SEAL.]

———— ————,

Secretary of the ——— Water Users' Associatio

FORM B.

Lands in private ownership.

Application No. ——.
Water right ———. Project ———.

Act of June 17, 1902 (32 Stat. L., 388).

DEPARTMENT OF THE INTERIOR,
LAND OFFICE AT ———,
——— ———, *190-*

I, ——— ———, do hereby apply for a water right under the ——— proj subject to the provisions of the act of Congress approved June 17, 1902 (32 S L., 388), known as the reclamation act, and the rules and regulations establis thereunder, the water supplied in pursuance hereof to be used for the irriga of, and to be appurtenant to, ——— acres of irrigable land, as shown on p on file in this office approved by the Secretary of the Interior, within the described as follows:

section ——, township ——, range ——, ——— meridian, an area of — acres.

The amount of water to be furnished hereunder shall be ——— acre-feet water per annum per acre of irrigable land, as aforesaid, measured at the la or so much thereof as shall constitute the proportionate share per acre from water supply actually available for the lands under said project: *Provided*, T the supply furnished shall be limited to the amount of water beneficially used said irrigable land.

I agree to pay for said water right the sum of $——— per acre for the s area of irrigable land, in —— annual installments, and to pay promptly wl due the annual installments and the maintenance and operating charges d assessed against said land on account of said water right.

I further agree that upon my failure to comply with the terms of s reclamation act this application shall be subject to cancellation with the feiture of all rights acquired thereunder and all payments made thereon.

This application must bear the certificate, as hereto attached, of the wa users' association under this project, which has entered into contract with Secretary of the Interior.

If the Secretary of the Interior has made no contract with a water use association under this project, I agree to file, upon his direction, evidence membership in the water users' association organized under the said proje in default of which this application shall be subject to cancellation with forfeiture of all rights acquired thereunder and of all payments made thereon

And, being duly sworn, I further depose and say that my post-office address is ———; that I am a bona fide resident upon said land (or an occupant thereof, residing in the neighborhood, namely, upon section ——, township ——, range ——, ——— meridian, a distance in a direct line of —— miles therefrom); that I hold the following interest in the said tract:

———————————————————————————————

———————————————————————————————

———————————————————————————————

———————————————————————————————

as duly shown upon the records of ——— County, ———; that I have made no other application, now uncanceled, for a water right under said act of Congress, appurtenant to land now owned or claimed by me except as follows: Application No. ——, ——— project, ——— of ———, for ——— section ——, township ——, range ——, ——— meridian, an area of ——— acres and containing ——— acres of irrigable land as determined by the Secretary of the Interior; and that the present application is made in my own behalf and not at the instance or for the benefit of any other person or any association or corporation, either directly or indirectly.

It is further understood and agreed that the evidence of ownership of this water right shall not be issued by the United States unless fee-simple title to said land is vested in me at the time when the final payment hereon is due, in default of which this application shall be subject to cancellation with the forfeiture of all rights thereunder and of all moneys paid thereon.

——— ———, *Applicant.*

STATE OF ———, *County of* ———, *ss:*

Subscribed and sworn to before me this —— day of ———, 190—.

[SEAL.] ——— ———,

——— ———.

(My commission expires ———.)

[This affidavit may be sworn to before any officer authorized to administer an oath.]

If the Secretary of the Interior has entered into a contract with a water users' association under the project, the following certificate must be filled out:

——— ———, *190—.*

I hereby certify that the applicant for this water right has duly subscribed for the stock of this association for the lands described herein, and that all assessments levied against said stock by this association have been fully paid up to date.

[CORPORATE SEAL.] ——— ———

Secretary of ——— Water Users' Association.

CIRCULARS.

From time to time, as regulations are promulgated or decisi rendered affecting the conduct of work under the reclamation circulars embodying the information are prepared in the office of chief engineer and sent out to the various men in the field.

It is important that these circulars be carefully read and preserv for reference. A separate book should be kept for the purpose engineers, and the circulars should, after reading, be pasted there and a subject index made and kept up to date.

In the following pages the substance of recent circulars of imp tance is repeated for convenience of reference and in order that information may be thus brought to the attention of new employe

RAILROAD TRANSPORTATION RATES.

The act of Congress of March 3, 1905 (Public, No. 192), provi that any moneys refunded in connection with the operations un the reclamation act shall be covered into the reclamation fun therefore any refund of freight rates that may be obtained w reduce the cost of construction and promote the development a settlement of the lands under the projects.

It has therefore been possible to enter into contracts with a nu ber of railroad companies providing for the transportation reduced rates of machinery, materials, and supplies used on t projects. The form of construction contract now in use by the R lamation Service provides that contractors shall afford to the en neer opportunity to obtain copies of the expense bills on all m chinery, materials, and supplies shipped to or from the project f use in connection with the work. These expense bills are transmitt to the railroad company by the engineer in charge of the proje and the railroad company pays to the engineer, by check drawn the order of the Secretary of the Interior, the difference betwe the amount paid by the contractor and the charges at the rate co tracted for between the railroad company and the United States.

The contracts do not cover transportation of provisions, clothir or supplies for laborers or others engaged on the work, nor artic produced or carried in stock in the local market.

Question having arisen as to whether the provisions of t interstate-commerce law, which forbid common carriers to gra concessions from their published rates, affect certain agreemer between the United States and various railroad companies in whi

the latter promise to transport, at one-half their published rates, materials and machinery required by the United States or by parties contracting with the United States, for use upon the irrigation systems under construction in the arid West, the opinion of the Attorney-General was requested, and the following is quoted from his letter of April 20, 1905, upon the subject:

It is perfectly plain, I think, that the intention of section 22 of the act to regulate commerce was to give express sanction to any arrangements between the United States, State, or municipal governments, and railroad companies by which those governments might relieve themselves of the cost of transportation in whatever form it might assume, and the section should be construed to give effect to that intention. It is, therefore, immaterial whether the property transported belonged to the United States at the time of shipment or whether it have subsequently become the property of the United States in the particular shape in which it was shipped. It is sufficient that it entered into the construction of a public work of the United States, and that the cost of its transportation was a part of the final cost of that work to the United States.

The issue, then, narrows down to this: Does the United States, in point of fact, receive in the end the whole of the concession in freights granted under these contracts?

It can not, of course, be stated in advance, as a presumption of fact covering all cases which may arise under this arrangement, that the United States will receive the whole of the concession and the contractor none, for that would be to presume not only that the contractor's bid will be less than it would have been if he had had to pay the published rates, but that it will be less by an amount equal to the freight reductions allowed him. On the other hand, however, it certainly can not be presumed that under no circumstances will the United States receive the whole concession; that is to say, that in no case will the contractor make full allowance in his bid for the reduced freight rates. The strong probability is that he will not leave any advantage from that source in the hands of his competitors. In other words, then, whether or not the United States receives the whole of the concession and the contractor none is a question of fact which must be decided in each case especially, as the answer may differ in different cases. My conclusion upon the questions you propound, therefore, is this: That in those cases where the fact is that the United States receives the whole of the concession and the contractor none, then neither the spirit nor the letter of the act to regulate commerce has been violated, but that in those cases, if any, where that is not the fact the operation of the agreements which have been drawn in question would result in the violation of section 2 of the act. Being a question of fact, and one that, if it shall ever properly arise it must arise in the administration of your Department, your determination of the question will be binding so far as the executive branch of the Government is concerned.

TRANSPORTATION AGENT.

It is desired that all matters relating to transportation and the handling of bills of lading be referred to F. H. Cass, transportation agent, 876–877 Federal building, Chicago, Ill.

When possible, the transportation agent will be required to attend personally to all shipments of freight, especially material purchased f. o. b. at any point on the Missouri River or east thereof. Engineers

making purchases in this territory should furnish Mr. Cass with co of orders and such memoranda as will enable him to properly prepa the bills of lading and to ship in accordance with the wishes and nee of the engineer. When it is not possible for this business to attended to from the Chicago office, the engineer should furnish t transportation agent with memoranda of the shipping orders wh they are placed, so the shipments may be expedited.

LAND AND LEGAL MATTERS.

Engineers in charge of projects should keep the chief engine advised of all work relating to land or legal matters which may necessary. They should give notice as long in advance as possib concerning assistance required in work of this character, in order th men regularly in the service may be detailed, or that instructions m be given for the employment of field assistants. Detailed instru tions concerning this phase of the work will be found on pages 96 104 of Water-Supply Paper No. 93. Later instructions modifyi part of the procedure there outlined are printed in the late edition "Blank for report on negotiations for purchase of lands," For 9–281, and are as follows:

PURCHASES OF LANDS.

The proper method of procedure in making purchases of lands under the re lamation act, in pursuance of the various rulings made by the Department the Interior and the Department of Justice, is substantially as stated belo In some cases, however, deviations may be necessary in certain details.

1. As soon as possible after it has been ascertained that the property will b required, the engineer in charge should forward to the office of the chief eng neer the following papers:

(*a*) Form 9–276, contract of sale, or memorandum of terms of proposed pu chase.

(*b*) Form 9–281, report on land agreement.

(*c*) Certificate that the land is necessary for the purposes authorized by th reclamation act and that the price agreed upon is reasonable, together with recommendation that the purchase be made. This certificate should also conta other available information relative to the purchase not given in Form 9–281.

These papers will be submitted to the Secretary of the Interior for approv as to the price and terms of purchase.

2. When the agreement to sell has been approved by the Secretary, the eng neer will notify the vendor thereof that he should, pursuant to said agreemen procure and have recorded, where proper for record, any assurances of title a affidavits which may be necessary and proper to show clear, unincumber title in him. This will fix the date from which time may be counted in fav of the United States for extension of the option as provided in the agreemen in case it be found necessary to do so. An abstract of the title should procured, together with proper certificates as to the status of the records co cerning lands, judgments, and taxes. The abstract, certificates, and form deed which it is proposed to execute, referred to in next paragraph, should submitted to the United States attorney for the district, after the engineer h

received notice that instructions have been issued to the former by the Attorney-General to examine and report on the subject of titles. These instructions will be requested by this office after the receipt of information from the engineer that the purchase of lands has become necessary.

3. The ordinary form of warranty deed or its equivalent in general use will be acceptable to the Department, only one material change being required, viz, the insertion of the italicized words in the clause to the following effect usually found in such deeds: "for and in consideration of ——— dollars to him in hand paid *in pursuance of the provisions of the act of June 17, 1902 (32 Stat. L., 388)*, by the said party of the second part," etc. The grantee or second party must be the United States, and the words "heirs, executors, administrators, successors," etc., when referring to the second party, should be stricken out, and the sentence should read "the party of the second part and its assigns." One copy of the proposed form of deed should be transmitted with the abstract to the United States attorney, and one copy should be retained by the engineer, to be executed by the vendor when the purchase is authorized by the Secretary of the Interior. A quitclaim deed will be acceptable in case title in fee is not vested in the vendor.

4. The United States attorney will forward the abstract and form of deed to the assistant attorney-general for the Interior Department, with his opinion thereon, in accordance with instructions from the Attorney-General.

5. The engineer in charge will notify the chief engineer as soon as the abstract and form of deed have been forwarded to the assistant attorney-general, and will state, if possible, the tenor of the report made by the United States attorney.

6. The assistant attorney-general will render an opinion upon the title, and upon approval thereof by the Secretary of the Interior the purchase will be authorized, if the title is found satisfactory. In case the title is found to be imperfect, the papers will be returned for the necessary corrections, and the abstract should then be brought up to date and again submitted for reexamination.

7. Upon notice of authorization, the payment can be made by a local disbursing officer, if one is available, taking vouchers in the usual way. In other cases payment will be made through the Treasury Department, for which purpose there should be forwarded to the Washington office the executed deed, duly recorded, and certificates that nothing has been placed on record adversely affecting the title as to conveyance, judgments, or taxes since the date of the abstract; in other words, the abstract should be brought up to the date of the record of the deed to the United States. No voucher is needed if payment is made through the Treasury Department. The described certificates and the recorded deed must be transmitted with the local disbursing officer's accounts if the payment is made by him.

8. In the case of the desert-land entry, when the Secretary has approved the purchase of the possessory rights of an entryman, the certificate of the recorder of land titles in the county where the land is situated should be obtained, showing that he has searched the records of his office, and stating whether any instrument of conveyance, assignment, or mortgage of the right obtained by the entry referred to there appears.

9. In the case of land covered by a homestead of desert-land entry a relinquishment to the United States is sufficient, and a certificate should be obtained from the register and receiver of the local land office, showing that the entry was valid and subsisting at the time of the relinquishment, and that it has been relinquished and canceled on the records of the land office.

10. In the public-land States improvements by entrymen are generally regarded as personal property, subject to taxation, and before paying for land

to be acquired by relinquishment, the certificate of the officer having charge of the tax records in the county should be obtained showing the condition of the property in respect to levy and payment of taxes for the years since the entry.

11. This form (9-281) may be used as far as it is applicable in making a report of negotiations not concluded, all necessary additional information being given under heading No. 6, when for any reason it is advisable that the matter be further considered by the engineer in charge before final agreement. In this case it should be noted conspicuously on the first page and in the brief on back that it is a report of pending negotiations.

12. The person engaged in right-of-way negotiations or in negotiations for the purchase of lands will make monthly reports to the engineer in charge of the particular project, to be forwarded to the chief engineer at Washington, D. C.

13. An agreement of sale may be made with any person owning the land in his own right, or with a trustee under a power in a deed, or with a person holding a power of attorney from the owner authorizing him to do so, or with an executor under power in a will. Certified copy of the evidence of authority must accompany the papers.

14. The husband and wife must join in the agreement except where the local land laws or the conditions under which the property is held do not require it. It is better, however, to obtain in every case the signatures of both husband and wife. The agreement must state whether the vendor is married or single, a widow or widower.

15. An administrator or an executor without a power to sell in the will has no authority to make a contract for the sale or conveyance of land or of a right of way thereon. In case of the death of the owner without a will, the real estate descends to the heirs; if he dies leaving a will, the real estate goes to the devisees, subject in both cases to the payment of debts of the decedent. The heirs or devisees must all join in the agreement.

16. Neither the guardian of a minor nor the guardian of an insane person has a right to contract to sell or convey the real estate of his ward without special authority from the proper court.

17. Before negotiations for the purchase of any tract are begun it is important to learn whether the land has been offered for sale, and at what time and price; also what price the present owner paid for the land.

18. Special conditions and limitations may be added, when necessary, to the printed forms of contract in reference to possession of premises, growing of crops, etc., pending final conveyance, but these conditions should be avoided as far as possible, and the time limit of the contract should be fixed with reference to these matters. Ample time should be given in the contract for the preparation of an abstract of title and for consideration of the same by the officials at Washington, D. C.

19. For a general discussion of this subject, see pages 96 to 100 of Water-Supply Paper No. 93.

PURCHASE OF POSSESSORY CLAIMS ON PUBLIC LANDS.

Attention is called to the following quotation from a letter of the Secretary of the Interior, dated January 25, 1905, regarding settlement or possessory rights of parties who have made entries or filings under the public-land laws:

As the legal and equitable title is in the United States to all public lands to which a mere inchoate right has attached, there is no outstanding legal or equitable title in such lands to purchase; but the improvements of the settlers

made upon such lands under authority of the public-land laws are a property right which can not be taken without compensation, which probably may include the enhanced value of the land by reason of the settler's cultivation and improvement.

The legal title passes from the United States only upon the issuance of patent; but an entryman, if he has complied with the law, acquires by his final certificate an equitable right, which is the equivalent of a patent so far as it affects his rights and interest. Such title or right can not be divested and acquired by the United States under the act of June 17, 1902 (32 Stat. L., 388), except by purchase or by condemnation in the manner provided by law. The effect of this ruling is that to acquire any rights asserted under the public-land laws, prior to the issuance of final certificate, it is necessary to pay only for the improvements—which probably may include the enhanced value of the land due to the claimant's cultivation and improvement—as there is no outstanding title to the land to be acquired.

RIGHTS OF WAY FOR CANALS AND DITCHES.

Engineers and others authorized to acquire rights of way for canals and ditches under the reclamation act should proceed as follows:

1. They should examine the lands and prepare a general map showing the position of the canals with reference to the land lines.

2. They should ascertain the essential facts as to ownership.

3. Owners of lands entered subsequent to October 2, 1888, should be served with notice (Form 9-263) in accordance with instructions on page 101, Water-Supply Paper No. 93, which should be carefully followed. In such cases no agreement or abstract of title is required. Where the lands are needed for other purposes than for canal or ditch right of way, they must be purchased or donated.

4. Where lands were entered prior to October 2, 1888, the owner or his representative should be seen and a fair and reasonable price agreed upon, or, if possible, a free grant should be obtained.

5. In cases under paragraph 4, Form 9-276 should be used. Where no payments are to be made, Form 9-277 should be used.

6. In all cases Form 9-281 should be filled out and should accompany Forms 9-276 and 9-277. The report should state all the facts, in order that the details of the purchase or agreement may be fully understood by the chief engineer.

7. When the purchase is decided upon, an abstract of title must be secured. An abstract must also be obtained when the land is donated, because the risk of construction can not be undertaken without the assurance that the consent of the actual owner and all parties interested has been secured. Abstracts may be paid for by the Reclamation Service when they are to be used in connection with purchases,

but not when they are to be used in connection with condemnati Appropriate arrangements may be made with the vendor as to f nishing abstract of title, either by him or by the Government.

8. Form of deed which the vendor proposes to execute should submitted.

9. In proceedings under paragraphs 7 and 8 the printed instr tions given in Form 9–281 (see p. 218) should be followed.

10. The agreement and report must be accompanied by a certific from the district engineer as to the necessity of the right of way a the reasonableness of the price, and must contain a definite reco mendation as to the purchase.

APPROPRIATION OF WATER.

On page 103 of Water-Supply and Irrigation Paper No. 93 dir tions are given for the proper filing of notices of appropriation water. Engineers are therein advised—

> to submit a copy to the United States district attorney, calling his attention the instructions of the Attorney-General, dated September 14, 1903, provid for giving advice to the engineers of the Reclamation Service concerning preparation of such notices, and requesting any suggestion which he may h to offer in regard to the form submitted.

It has been found necessary to caution engineers to follow this advi

In several of the reclamation States laws were enacted in 19 granting special privileges to the United States when appropriati water for the purpose of carrying out the provisions of the reclam tion act. These, together with the statutory law governing appr priations in the other reclamation States, are summarized below.

It is important to follow strictly the provisions of law and t local regulations in filing notices of appropriation.

In the States where special laws have been enacted to govern appr priations by the United States the specific language of the law shou be utilized and followed in giving the required notices.

The work required under the various statutes after filing notic differs under the various laws, and it is essential that the requiremen in each case shall be followed as closely as possible.

Nothing will be gained by filing these notices unless their form a the subsequent proceedings comply with the provisions of the la and, accordingly, these matters must be so ordered as to conform the law and the regulations in all particulars so far as it is possib under the operations of the reclamation act.

In Arizona a notice [a] of the proposed appropriation must be post at the place of intended diversion. A copy of the notice must

[a] Water-Sup. and Irr. Paper U. S. Geol. Survey No. 93, 1904, p. 103.

filed for record in the office of the recorder of the county or counties in which the diversion and other works are situated, and a copy of the notice must also be filed in the office of the secretary of the Territory. The works must be constructed within a reasonable time after posting and filing the notice.

In California a notice [a] of the proposed appropriation must be posted at the point of intended diversion, and a copy must be recorded in the office of the recorder of the county in which it is posted within ten days. Work must be begun within sixty days and prosecuted diligently and uninterruptedly to completion.

In Colorado, within sixty days after commencing construction, statements and maps in duplicate must be filed with the State engineer for his approval. After approval by the State engineer the claimant must file duplicate map and statement thus approved in the office of the county clerk and recorder of the county in which the headgate of the canal or the reservoir is situated. Blank forms for this statement and directions for preparing maps can be obtained upon application to the State engineer. Engineers are requested to keep copies of such forms and directions on file in their office and to follow them carefully in making an appropriation of water.

In Idaho an application must be made to the State engineer for permission to make an appropriation. Engineers are requested to keep on file in their office copies of printed forms and directions furnished by the State engineer, and are cautioned to abide by all the rules and regulations of the State engineer's office in making an appropriation.

In Kansas a notice [a] of the proposed appropriation must be posted at the point of intended diversion, and within ten days thereafter a copy of the same must be posted in a conspicuous place in the office of the county clerk of the county in which the diversion is situated and be recorded by the county clerk. Work must commence within sixty days and be prosecuted diligently.

In Montana a notice [a] of the proposed appropriation must be posted at the point of intended diversion, and a verified copy must be filed within twenty days with the county clerk of the county in which the diversion is made.

By an act of the Montana legislature approved February 27, 1905, all appropriations made in behalf of the United States by persons duly authorized by the Secretary of the Interior shall be held valid for the period of three years after the filing of the notice as above described, and no part of the waters designated in the notice shall be subject to other appropriation for three years unless a notice of abandonment of the irrigation project is filed under authority from

[a] Op. cit., p. 103.

the Secretary of the Interior with the county clerk and recorder of the county in which the original notice was filed.

In Nevada the same procedure must be followed as in Idaho.

In New Mexico, by an act approved March 16, 1905, it is provided that whenever the proper officer of the United States shall notify the State engineer that the United States intends to utilize certain specified waters, such waters shall not be subject to further appropriations, except in so far as formally released in writing by a duly authorized officer of the United States.

In North Dakota, by an act approved March 1, 1905, it is provided that whenever the proper officer of the United States shall notify the State engineer that the United States intends to utilize certain specified waters, such waters shall not be subject to other appropriation for a period of three years from the date of said notice, except in so far as formally released in writing by the proper officer of the United States. Before the expiration of the three-year period plans of the proposed work must be filed in the office of the State engineer.

In Oklahoma the statutory provisions covering this subject are the same as those in North Dakota, stated above.

In Oregon, whenever the proper officer of the United States shall file in the office of the State engineer a written notice that the United States intends to utilize certain specified waters, such waters shall not be subject to further appropriation for a period of three years from the date of filing such notice, within which time final plans of the proposed works must be filed with the State engineer. Construction must be authorized by the United States within four years of the date of the original notice. No part of the waters so appropriated shall be subject to other appropriation within the period stated above, unless formally released in writing by a duly authorized officer of the United States, which release shall be filed in the office of the State engineer.

In South Dakota the statutory provisions covering this subject are the same as those in North Dakota, stated above.

In Utah the same procedure must be followed as in Idaho.

In Washington, by an act approved March 4, 1905, it is provided that whenever a duly authorized officer of the United States shall notify the commissioner of public lands that the United States intends to make examinations or surveys for the utilization of certain specified waters, the waters so described shall not be subject to other appropriation for a period of one year from the date of receipt of such notice by the commissioner of public lands, unless formally released in writing by a duly authorized officer of the United States. If, before the expiration of the one-year period, a duly authorized officer of the United States shall certify in writing to the commis-

sioner of public lands that the project contemplated in such notice appears to be feasible and that the investigation will be made in detail, the waters specified in such notice shall not be subject to other appropriation for the further period of three years following the date of receipt of such certificate, and such further time as the commissioner of public lands may grant upon application of a duly authorized officer of the United States and notice thereof first published once a week for four consecutive weeks in a newspaper published in each county in which the works are to be constructed.

In Wyoming the same procedure must be followed as in Idaho.

INFORMATION CONCERNING LANDS UNDER RECLAMATION PROJECTS.

The following is a copy of a letter from the Secretary of the Interior, dated March 3, 1905, addressed to the Director of the Geological Survey, relative to the establishment of bureaus where information may be had concerning public lands subject to disposal under the provisions of the reclamation act:

On the 10th ultimo you reported to the Department on a letter of January 26, 1905, from George H. Maxwell, who urged the establishment of bureaus of information in connection with irrigation projects, to answer inquiries relative to the location of lands subject to disposal to actual settlers under the provisions of the reclamation act of June 17, 1902 (32 Stat. L., 388).

Your report has been duly considered and in a letter of even date to the Commissioner of the General Land Office I have directed him to instruct the registers and receivers of the several land districts in which the projects are located to give full information relative to public lands included in the projects and subject to disposal under the act mentioned to all parties making inquiry with a view to actual settlement and to keep the engineers of the Reclamation Service fully informed by correspondence of the conditions pertaining to such lands.

In view of the fact that the work of construction of several of the projects under the act is well advanced I direct that you instruct the engineers of the Reclamation Service in charge of the various projects to keep the registers and receivers of the land districts in which the projects are located fully informed by correspondence respecting the condition and progress of the work of construction and to inform inquirers that, without cost, full and reliable information respecting the public lands to be disposed of under the act may be obtained from the register and receiver of the land district in which the lands are located.

You are also directed to authorize the chief engineer of the Reclamation Service to announce with each project that information concerning lands to be irrigated thereunder will be given officially by the register and receiver of the land district on request therefor addressed to them at the proper time.

By this cooperation of the officers of the Reclamation Service and the registers and receivers of the local land offices it is believed that all persons desiring to make entries of lands to be irrigated will be enabled to secure all necessary information respecting such lands.

CONTRACTORS' BONDS.

The Secretary of the Interior, in letter dated April 26, 1905, states that—

Every corporation authorized to transact business as sole surety under the terms of the act of August 13, 1894, is required to file in the office of the Secretary of the Interior the following papers:

(1) Evidence that it has obtained authority from the Attorney-General under the act above mentioned to act as sole surety on bonds in matters affecting the United States.

(2) Evidence of the election of general officers of the company for each year, with their names.

(3) Names of the persons in the several judicial districts of the United States authorized to accept service of process on behalf of the company.

(4) Names of the parties, however designated, authorized to execute bonds for and on behalf of the corporation in places other than its home office.

(5) A copy of its quarterly financial statement as filed in the Department of Justice.

In cases where surety companies have already filed with the Department the evidence and statements above mentioned, duplicates need not be furnished, but in lieu thereof a certificate may be appended to the bond stating that the papers are on file in the office of the Secretary of the Interior.

LIABILITY TO SUBCONTRACTORS.

The question of withholding final payment due under a contract in connection with the Truckee-Carson project, in Nevada, by reason of a claim preferred by a subcontractor for supplies and labor furnished, was the subject of an opinion rendered by the assistant attorney-general for the Department of the Interior, dated February 6, 1905, and approved by the Secretary the same day, wherein it was held that a mechanic's lien would not attach in favor of the subcontractor on work completed under the contract; that the Government incurred no liability by paying to the contractor the balance due under his contract; and that there is no obligation on the part of the Government to aid in the collection of such claims other than as provided by the act of August 13, 1894 (28 Stat. L., 278).

The said act provides that the bond required of parties entering into contracts with the United States in the prosecution of public works shall contain an additional obligation to make prompt payment to all persons furnishing supplies and labor in the conduct of the work, and that such persons may bring suit in the name of the United States, for their benefit, against the contractor and sureties, and prosecute the same to final judgment.

The opinion cited rulings of the United States Supreme Court to the effect that the United States can not be subjected to legal proceedings at law or in equity without its consent, and then only within the authority granted by some act of Congress; and that such exemption

extended to the property of the United States, there being no distinction between suits against the Government directly and against its property.

EXTENSION OF TIME ON CONTRACTS.

The following is a copy of a letter to this office from the Secretary of the Interior, dated April 1, 1905, which is self-explanatory:

With respect to existing and future contracts in connection with reclamation projects under the act of June 17, 1902 (32 Stat. L., 388), I direct that you instruct the engineers in charge of the various projects that whenever it becomes evident that the work covered by a contract can not be completed within the time fixed therein, they notify the contractor that any application for extension of time must be accompanied by the formal consent of the sureties thereto and lodged with the Department in ample time for the allowance of the application, if such action may be determined on, prior to the expiration of the contract.

PAYMENTS FOR EXTRA WORK.

Vouchers for extra work should be prepared and the items entered thereon in the following form:

EXTRA WORK.

Labor and materials as per attached itemized statement:

Actual cost of labor and materials..... $——

Fifteen per cent added, as per paragraph —— of contract..... ——

To the voucher should be attached two papers:

(1) Itemized statement of labor and materials, with engineer's certificate as follows:

I hereby certify that the above statement of cost of labor and materials is correct, and that the said extra work was performed in accordance with my instructions of ———, and that the same has been satisfactorily performed.

(2) Copy of letter to contractor authorizing the extra work.

In case the contract makes no provision for the added 15 per cent, or makes it necessary to insert other items, the voucher should be modified accordingly.

RENT OF OFFICES.

The Comptroller of the Treasury having held that no payments for rent should be made unless based upon a formal lease, forms of lease for office buildings for the Reclamation Service have been prepared, differing only in regard to the lessor, the forms being applicable, severally, to the cases of an individual, a firm, and a corporate lessor. Copies of these forms may be obtained on application to the chief engineer.

Each engineer of the Reclamation Service in charge of an office is authorized by the Director of the Geological Survey to sign such a lease, subject to the approval of the Secretary of the Interior.

PURCHASE OF ARMY STORES.

By authority granted by the Secretary of War, April 27, 1905, chiefs of parties are permitted to purchase commissary stores and quartermaster supplies, including officers' supplies, for official, camp, and for personal use, at any of the garrisoned posts enumerated below, provided such stores can, in the opinion of the commanding officers, be spared. Cash is to be paid for both classes of supplies in order that the proceeds received by the post commanders from such sales may be returned and again expended by the War Department for additional purchases during the same fiscal year. The price of quartermaster supplies will be contract price plus 10 per cent. The price of commissary stores will be contract price plus 10 per cent to cover waste in transit and an additional amount to cover cost of transportation. Party chiefs applying for such stores at garrisoned posts will show cards of identification, signed by the Secretary of the Interior and countersigned by the Director of the Geological Survey.

Quartermaster stores include practically all articles used in camp and personal equipment, such as tents, harness, vehicles, shovels, axes, cots, blankets, leggings, gloves, cutlery, tableware, forage, etc. Commissary stores include all varieties of subsistence supplies and such toilet articles as towels, soap, etc.

The following garrisoned posts are most accessible:

Adams, Fort, Newport, R. I.
Allegheny Arsenal, Pittsburg, Pa.
Apache, Fort, Arizona.
Assiniboine, Fort, Mont.
Barrancas, Fort, Fla.
Bayard, Fort, N. Mex.
Bliss, Fort, El Paso, Tex.
Boise Barracks, Boise, Idaho.
Brady, Fort, Sault Ste. Marie, Mich.
Brown, Fort, Brownsville, Tex.
Casey, Fort, Port Townsend, Wash.
Caswell, Fort, Southport, N. C.
Clark, Fort, Brackett, Tex.
Columbus Barracks, Columbus, Ohio.
Crook, Fort, Nebr.
D. A. Russell, Fort, Wyo.
Davis, Fort, Nome, Alaska.
Des Moines, Fort, Des Moines, Iowa.
Douglas, Fort, Utah.
Duchesne, Fort, Utah.
Du Pont, Fort, Delaware City, Del.
Egbert, Fort, Eagle, Alaska.
Ethan Allen, Fort, Vt.
Gibbon, Fort, Tanana, Alaska.
Grant, Fort, Ariz.
Hamilton, Fort, N. Y.
Harrison, Fort, Mont.
Hot Springs, U. S. Gen. Hosp., Ark.
Huachuca, Fort, Ariz.
Jackson Barracks, New Orleans, La.
Jay, Fort, New York City.
Jefferson Barracks, St. Louis, Mo.
Keogh, Fort, Mont.
Lawton, Fort, Interbay, Wash.
Leavenworth, Fort, Kans.
Lincoln, Fort, Bismarck, N. Dak.
Liscum, Fort, Alaska.
Logan, Fort, Colo.
Mackenzie, Fort, Sheridan, Wyo.
Madison Barracks, Sackett Harbor, N. Y.
Mason, Fort, San Francisco, Cal.

McHenry, Fort, Baltimore, Md.
McIntosh, Fort, Laredo, Tex.
McKinley, Fort, Portland, Me.
McPherson, Fort, Ga.
Meade, Fort, S. Dak.
Missoula, Fort, Mont.
Monroe, Fort, Va.
Morgan, Fort, Mobile, Ala.
Moultrie, Fort, Moultrieville, S. C.
Myer, Fort, Va.
Niobrara, Fort, Nebr.
Oglethorpe, Fort, Dodge, Ga.
Plattsburg Barracks, Plattsburg, N. Y.
Porter, Fort, Buffalo, N. Y.
Presidio of Monterey, Cal.
Presidio of San Francisco, Cal.
Reno, Fort, Okla.
Riley, Fort, Kans.
Robinson, Fort, Nebr.
Rosecrans, Fort, San Diego, Cal.
Sam Houston, Fort, Tex.
Sheridan, Fort, Ill.
Sill, Fort, Okla.
Snelling, Fort, Minn.
Stevens, Fort, Oreg.
St. Michael, Fort, Alaska.
Thomas, Fort, Newport, Ky.
Vancouver Barracks, Wash.
Walla Walla, Fort, Wash.
Washakie, Fort, Wyo.
Washington Barracks, D. C.
Wayne, Fort, Detroit, Mich.
Whipple Barracks, Prescott, Ariz.
W. H. Seward, Fort, Haines Mission, Alaska.
Wingate, Fort, N. Mex.
Yellowstone, Fort, Mammoth Hot Springs, Wyo.
Wright, Fort, Spokane, Wash.

REPORTS ON OPENING OF BIDS.

In order to secure uniformity and completeness in the reports of boards of engineers designated to open bids for work or materials in connection with reclamation projects, the following suggestions should be adhered to as closely as possible:

The report should be in duplicate and should include a statement that the bids were opened at a certain time and place (being the time and place mentioned in the advertisement), and that all the bids then received are transmitted with the report.

All the papers received with the proposals should be transmitted to the chief engineer, including the envelopes in which the bids were received.

On the outside of each envelope should be indorsed the amount of the certified checks submitted by the bidder, and the number, if more than one.

The report should also be accompanied by an abstract, in duplicate, of all the proposals received. The names of the bidders and the information given concerning each bid should be entered on this abstract in the order of the amounts of the bids—the lowest first, then the second lowest, and so on.

The report should also contain a specific recommendation as to the award of the contract, and if deemed advisable to let the contract to the next lowest bidder in case the lowest fails to qualify, an alternative recommendation should be made.

If recommendation is made that the contract be awarded to any

other than the lowest bidder, the reason for such reco
should be stated.

The report should be in such form that it can be subm
Secretary with the Director's letter of recommendation i
action to be taken, if deemed advisable.

It is desirable that the board prepare extra copies of tl
of the bids and forward them to the technical papers whic
the advertisements and which make a practice of printin
of bids, unless there is some reason for temporarily withl
information. The chief engineer should be informed of
of any publications to which this information is sent.

All bids withdrawn in the manner contemplated by th
tions and all bids not received within the time and at the p
tised should be promptly returned by the board unopened.

Water-Supply and Irrigation Paper No. 93, pages 71–8
regulations of the Indian Office concerning the openin
which should be of assistance to the boards of engineers in
their reports.

STANDARD PROGRESS REPORT COLORS.

In the preparation of progress maps and diagrams, Wins
water colors, according to the following table, are the stanc
ress colors for the Reclamation Service, and should be used

Colors for progress drawings, by months.

Months.	Colo
January	Sepi
February	Verr
March	Prus
April	Deep
May	Eme
June	Indi
July	Indi
August	Sap
September	Gam
October	Scar
November	New

Fill in fly-leaf blank the first day level book is used, and give date on each page of notes.

For a given H. I., rodman's notes must be at least two lines lower down page than levelman's, and they should not turn over leaf at same time.

Give complete information regarding source from which initial elevation is copied.

Insert sums of fore and back sight, rod readings, and difference between them for each page of notes.

Commence each circuit on a separate page.

A bench mark should be established for each mile run. Standard bench marks (posts or tablets) should not average more than 3 miles apart.

See book of "Instructions" for further details concerning leveling work.

SECONDARY LEVELING.

The plumbing level is dispensed with, and the turning point used only when running over muddy roads or soft ground. The notes are kept in duplicate and in about the same way as for the primary work, except that the lengths of sights are not usually entered and the readings are recorded to hundredths instead of thousandths of a foot. The lengths of sights are not limited and may be as long as can be readily taken.

Benches should be frequently left along the line and should be well placed and well described. Elevations of all points, such as road corners, high and low places, bridges, and water levels should be determined and neatly painted in large white figures, the elevation to the nearest foot only to be used. The outfit for each party consists of 15-inch level and double extension Philadelphia rod, notebook, No. 4 pencils, hatchet, chisel, 50-foot cloth tape, paint can, field glasses, copper nails, and, when necessary, a turning point.

The amount of secondary leveling necessary depends largely on the character of the country. In the rougher sections the valleys should be leveled and along the ridges the lines should be carried until the brow of the hill is reached, when they should be dropped. In gently rolling country it is advisable to follow nearly every road, secondary roads receiving attention as well as others when they are much over a mile apart. In extremely level sections, as in old lake beds, coastal plains, etc., only such lines should be run as will determine contour crossings. By sighting the level to buildings or other objects it can be determined whether there is sufficient rise or fall to warrant carrying the line through.

In marking up elevations for the topographer the number required

depends upon the nature of the country; thus, in the rougher regions few are required, while in sections where the ground is gently rolling the elevations should be numerous, and in extremely level sections each contour crossing should be marked. In all cases every road corner passed should be marked and at all good-sized streams both the bridge level and the water level must be painted up.

Every effort should be made to save time. The instrument should be approximately leveled by manipulating the tripod legs, getting ground elevations under the instrument by placing the rod alongside, sighting to the rodman's head, or shoulders, rather than undertaking to set the target by signals, in very long sights, or when the light is poor, and many others that a good levelman will discover. No limit of error is prescribed for this work, the general understanding being that a closure within a fifth of a contour interval is sufficient.

CORRESPONDENCE.

LETTERS.

Brief letters of inquiry are frequently sent to engineers in the field, the answers to which can be given in a few words. It is important to keep down the volume of correspondence and typewriting, and in particular to avoid writing new letters which simply repeat the question and give the answer. Wherever possible, engineers should indorse upon the bottom of the original letter the appropriate reply in a few words and send this back to the Washington office. This can frequently be done with saving of time and energy and reduction of the amount of material to be handled and filed.

When the matter is of such importance that the engineer desires to keep a copy of his statement, this simple method is not advisable, but in the majority of cases the information is not of such a character that a copy need be kept.

TELEGRAMS.

The Washington office frequently receives telegrams which are almost unintelligible and which require a most careful study to determine the probable meaning. Mistakes in interpretation of such telegrams are not rare. To correct the difficulty, all persons sending telegrams should prepare their draft without punctuation or capitalization, and then read this draft carefully to see whether the message as thus written is intelligible or is capable of more than one meaning. All messages are, of course, received without punctuation or capitalization, and frequently the last word of one sentence, when transferred to the beginning of the next, completely alters the sense.

DISMISSALS OF EMPLOYEES BEFORE END OF PROBATIONARY PERIOD.

The following is a copy of a letter from the Secretary of the Interior, dated March 27, 1905, addressed to the Director of the Geological Survey, in regard to the proper course to be pursued in dismissing incompetent persons prior to the expiration of the probationary period of their employment:

Referring to your communication of the 23d instant, subject "Dismissals prior to expiration of probationary period" of employees belonging to field parties in the Reclamation Service, and inclosing with your said communication a copy of a letter addressed to you by the chief engineer, dated the 21st instant, on the same subject, I have to advise you that, after informal conference with the Civil Service Commission, the proper course to pursue in such cases would be to suspend incompetents pending the service of notice on them of charges and final action thereon by the Department. Responsible officers in the field may be given this authority with instructions to report promptly all such cases where suspensions are made for inefficiency.

HOLDING OF OTHER OFFICES FORBIDDEN.

Following are copies of Executive orders dated January 17 and 28, 1873, on the subject of the incumbents of Federal offices holding or accepting offices under State or Territorial governments or under the charter or ordinances of municipal corporations:

Whereas it has been brought to the notice of the President of the United States that many persons holding civil office by appointment from him or otherwise, under the Constitution and laws of the United States, while holding such Federal positions accept offices under the authority of the States and Territories in which they reside, or of municipal corporations, under the charters and ordinances of such corporations, thereby assuming the duties of the State, Territorial, or municipal office at the same time that they are charged with the duties of the civil office held under Federal authority; and

Whereas it is believed that, with few exceptions, the holding of two such offices by the same person is incompatible with a due and faithful discharge of the duties of either office; that it frequently gives rise to great inconvenience and often results in detriment to the public service, and, moreover, is not in harmony with the genius of the Government:

In view of the premises, therefore, the President has deemed it proper thus and hereby to give public notice that from and after the 4th day of March, A. D. 1873 (except as herein specified), persons holding any Federal civil office by appointment under the Constitution and the laws of the United States will be expected, while holding such office, not to accept or hold any office under any State or Territorial government, or under the charter or ordinances of any municipal corporation; and, further, that the acceptance or continued holding of any such State, Territorial, or municipal office, whether elective or by appointment, by any person holding civil office as aforesaid under the Government of the United States other than judicial offices under the Constitution of the United States, will be deemed a vacation of the Federal office held by such

person, and will be taken to be, and will be treated as, a resignation by such Federal officer of his commission or appointment in the service of the United States.

The offices of justices of the peace, of notaries public, and of commissioners to take the acknowledgment of deeds, of bail, or to administer oaths shall not be deemed within the purview of this order and are excepted from its operation, and may be held by Federal officers.

The appointment of deputy marshal of the United States may be conferred upon sheriffs or deputy sheriffs. And deputy postmasters, the emoluments of whose office do not exceed $600 per annum, are also excepted from the operations of this order, and may accept and hold appointments under State, Territorial, or municipal authority, provided the same be found not to interfere with the discharge of their duties as postmasters. Heads of Departments and other officers of the Government who have the appointment of subordinate officers are required to take notice of this order, and to see to the enforcement of its provisions and terms within the sphere of their respective Departments or offices, and as relates to the several persons holding appointments under them, respectively.

Inquiries having been made from various quarters as to the application of the Executive order issued on the 17th January, relating to the holding of State or municipal offices by persons holding civil offices under the Federal Government, the President directs the following reply to be made:

It has been asked whether the order prohibits a Federal officer from holding also the office of an alderman or of a common councilman in a city, or of a town councilman of a town or village, or of appointments under city, town, or village governments. By some it has been suggested that there may be distinction made in case the office be with or without salary or compensation. The city or town offices of the description referred to, by whatever names they may be locally known, whether held by election or by appointment, and whether with or without salary or compensation, are of the class which the Executive order intends not to be held by persons holding Federal offices.

It has been asked whether the order prohibits Federal officers from holding positions on boards of education, school committees, public libraries, religious or eleemosynary institutions incorporated or established or sustained by State or municipal authority. Positions and service on such boards or committees, and professorships in colleges, are not regarded as "offices" within the contemplation of the Executive order, but as employments or service in which all good citizens may be engaged without incompatibility, and in many cases without necessary interference with any position which they may hold under the Federal Government. Officers of the Federal Government may, therefore, engage in such service, provided the attention required by such employment does not interfere with the regular and efficient discharge of the duties of their office under the Federal Government. The head of the Department under whom the Federal office is held will, in all cases, be the sole judge whether or not the employment does thus interfere.

The question has also been asked with regard to officers of the State militia. Congress having exercised the power conferred by the Constitution to provide for organizing the militia, which is liable to be called forth to be employed in the service of the United States, and is thus, in some sense, under the control of the General Government, and is, moreover, of the greatest value to the public, the Executive order of 17th January is not considered as prohibiting Federal officers from being officers of the militia in the States and Territories.

It has been asked whether the order prohibits persons holding office under the Federal Government being members of local or municipal fire departments; also, whether it applies to mechanics employed by the day in the armories, arsenals, and navy-yards, etc., of the United States. Unpaid service in local or municipal fire departments is not regarded as an office within the intent of the Executive order, and may be performed by Federal officers, provided it does not interfere with the regular and efficient discharge of the duties of the Federal office, of which the head of the Department under which the office is held will, in each case, be the judge. Employment by the day as mechanics or laborers in the armories, arsenals, navy-yards, etc., does not constitute an office of any kind, and those thus employed are not within the contemplation of the Executive order. Master workmen and others who hold appointments from the Government, or from any Department, whether for a fixed time or at the pleasure of the appointing power, are embraced within the operation of the order.

PRIVATE EMPLOYMENT FORBIDDEN.

Several inquiries have come to the chief engineer regarding the propriety of engineers or assistants of the Reclamation Service doing outside professional work. There are occasionally a few tempting opportunities of this kind where a considerable fee can apparently be earned with small outlay of time. The experience of the past has shown, however, that it is not good administration to permit the engineers to be diverted by outside professional work, and on this point the Secretary of the Interior is very definite. In his report for the year ending June 30, 1904, he says, on page 88:

The reclamation work must therefore be placed in the hands of men who for years have given the subject their best thought, and these men must be protected from external pressure and guarded from the possibility of selfish consideration. In the organic law of the Geological Survey it is provided that the Director and members shall have no personal or private interests in the lands or mineral wealth of the region under survey, and shall execute no surveys for private parties or corporations. This law applies to the Reclamation Service, which has been made a branch of the Geological Survey, and although the law may occasionally work hardship I believe that good administration requires its enforcement.

In the case of several men coming into the Service it was agreed that they should finish up the consulting work on which they had previously been engaged, but it is believed that the interests of the Service require that this work should be brought to a close at the earliest possible date.

FEES FOR OATHS.

Treasury Department Circular No. 57, April 22, 1905, gives the following schedule of fees which notaries public and justices of the

PERSONNEL OF THE RECLAMATION SERVICE

The report of the first conference of the engineers of the Recl tion Service (Water-Supply and Irrigation Paper No. 93) cont on pages 315–351, a list giving, in alphabetical order, the nam the principal men of the regular force of the Reclamation Service the salient facts concerning their education and experience.

The records of a considerable number of employees were not a able at that time, however, and many have since entered the Ser and these are listed below:

ADAMS, C. ROBERT, engineering aid. Address, Boston, Mass. Born, Bo Mass., November 30, 1884. Education, Boston public schools; Massachu Institute of Technology, S. B. Member M. I. T. Civil Engineering Soc 1904, rodman and instrument man, Massachusetts. Appointed in Reclama Service June 8, 1905.

AMBLER, J. OWEN, engineering aid. Address, Montrose, Colo. Born in tucky, May 18, 1883. Education, common schools and Missouri School of M 1903, draftsman for Steam Appliance Company, St. Louis. 1904–5, instru man on canal location with Reclamation Service in Colorado. March 18, appointed engineering aid in Reclamation Service.

AVAKIAN, JOHN CASPER, assistant engineer. Address, Los Angeles, Cal. in Harpoot, Armenia, March 1, 1875. Came to United States, June, 1 1889–1894, classical course in Cook Academy, Montour Falls, N. Y. 1894 classical course in Colgate University, Hamilton, N. Y. 1895–1897, lecture New England and Middle States and Canada. 1897–98, commercial travele New England States. 1898–1902, Rensselaer Polytechnic Institute, Troy, N. C. E. June, 1902, to January, 1903, draftsman for Lehigh Valley Railroa Buffalo, N. Y. February to March, 1903, locating engineer for Buffalo, kirk and Western Railroad. April to June, 1903, private office in Los Ang Cal. July, 1903, to February, 1905, draftsman, United States Reclama Service, on Yuma project. March 24, 1905, appointed assistant engin Reclamation Service.

BAKER, SHELDON K., hydrographic aid. Address, Washington, D. C. Bor Washington, D. C., July 6, 1880. Massachusetts Institute of Technology, de B. S., course in sanitary engineering. In 1901, with a firm of civil engine also draftsman under Isthmian Canal Commission. In 1902, traversen United States Geological Survey, in Montana. 1903, employed by Springf (Mass.) Special Water Commission as assistant engineer and chemist on exp mental filtration of public water supply. Also employed on bacteriological chemical analyses of water. March 23, 1904, appointed hydrographic aid Reclamation Service.

BALCH, LELAND RELLA, engineering aid. Address, Huntley, Mont. B Neillsville, Wis., March 10, 1883. Education, University of Wisconsin, B. in C. E. 1902–4, assistant to county surveyor of Clark County, Wis., du vacations. Appointed in Reclamation Service May 22, 1905.

BINGHAM, JOSEPH INKOFF, engineering aid. Address, Browning, Mont. Born, Lockwood, N. Y., December 11, 1877. Education, Starkey Seminary, N. Y., 1898. Graduated in sanitary engineering at University of Wisconsin, 1904. 1901–2, chainman, rodman, and levelman, Lehigh Valley Railroad. 1903, traverseman, United States Geological Survey. 1904–5, location and construction work, Chicago and Northwestern Railroad. Appointed in Reclamation Service May 1, 1905.

BRENNAN, MICHAEL SHELLY, engineering aid. Address, Chicago, Ill. Born in Rhode Island December 25, 1870. Education, Brown University, 1900, C. E. Summer of 1899, street and water departments, Providence, R. I. 1900–1903, inspector of concrete bridges, inspector of pile driving, and assistant engineer, Illinois Central Railroad. 1903–4, transitman and chief of party laying terminal tracks, St. Louis. 1904, inspector of reenforced concrete bridge work, Chicago, Ill. Appointed in Reclamation Service March 7, 1905.

BROTHERS, WALTER A., special disbursing agent. Born September 1, 1879. High school education. Entered Reclamation Service January 13, 1903. May 1, 1905, promoted to special disbursing agent and stationed at Casper, Wyo., on North Platte project.

BRUNDAGE, FRANK HOMER, assistant engineer. Address, Washington, D. C. Born at Oil City, Pa., August 21, 1877. Education, civil engineering, three years at Case School of Applied Science; one year at Cornell University. 1899, draftsman, Webster Camp, Lane Machine Company, Akron, Ohio. 1899–1902, aid, United States Coast and Geodetic Survey. 1902–3, computer, United States Coast and Geodetic Survey. March 5, 1903, transferred to computer, United States Geological Survey. July 1, 1904, promoted to assistant engineer.

BURRAGE, JOHN OTIS, assistant engineer. Address, Fort Laramie, Wyo. Born, Lowell, Mass., February 13, 1877. Education, four years student of civil engineering at Tufts College, class of 1900. Member Technical Society of the Pacific Coast; Junior American Society of Civil Engineers. 1899, in engineering office on Merrimac River, Massachusetts. 1900, engineer and draftsman American Ordnance Company, Bridgeport, Conn. 1901, with Union Iron Works, San Francisco, in drafting room. 1902–1905, draftsman, bureau of engineering, city engineer's office, San Francisco. Appointed in Reclamation Service May, 1905.

CALLISTER, THOMAS C., jr., engineering aid. Address, Fillmore, Utah. Graduate Agricultural College of Utah, B. S. in C. E. In 1902, measuring streams under Agricultural College Experiment Station. 1903, field assistant with Reclamation Service in Utah and Idaho. 1904, installing private telephone system connecting the towns of Millard County, Utah; also field assistant with Reclamation Service in Idaho and Utah. 1904–5, on construction work with San Pedro, Los Angeles and Salt Lake Railroad as office and field assistant. January, 1905, appointed engineering aid in Reclamation Service.

CARBERRY, RAY S., assistant engineer. Address, Mitchell, Nebr. Born, Secoo, Ill., May 3, 1873. Education, University of Illinois, School of Civil Engineering, B. S., 1895. 1895, city engineer on construction of sewer system. 1896, land and drainage surveying. 1896–97, city engineer, Monticello, Ill. 1897–98, drainage and dredge work in central Illinois. 1898–1900, engineer and general manager, Marysville Canal and Improvement Company, Idaho. 1901–2, levelman, instrument man, and assistant engineer Oregon Short Line. 1903, on grade reduction, Wabash Railroad, central Illinois. 1904, Wabash Railroad constructing World's Fair grounds terminals. 1904–5, instrument man Chicago and Northwestern Railroad Company, Chicago. Appointed in Reclamation Service April, 1905.

CARPENTER, WILLIAM T., engineering aid. Address, Pittston, Pa. Graduat Lehigh University, 1902, degree C. E. One year with Coast and Geo Survey, on hydrographic work. July 11, 1903, transferred to Reclam Service as engineering aid.

CASS, FRANK HENRY, transportation agent. Born in Alexandria, N. H. cated in rural schools. Engaged in railroad work from 1865 as news brakeman, telegraph operator, and agent on various railroads. From 188 1904 employed by the Chicago and Eastern Illinois Railroad as freight c agent, bill of lading clerk, contracting agent, and lumber agent. October 1904, appointed transportation agent in the Reclamation Service.

CAVIS, FRED L., special disbursing agent. Address, Boise, Idaho. Marysville, Ohio, December 23, 1879. Education, public and high schools. J ary 1, 1904, to May 1, 1905, stenographer and bookkeeper in Boise office. R mation Service. May 1, 1905, appointed special disbursing agent.

CLEGHORN, JOHN C., engineering aid. Born December 23, 1880, at Om Iowa. Graduated, 1899, from Onawa High School and, 1903, Iowa State Co with degree of B. Min. E. 1902, transitman, Yellowstone Park Improven 1903, mining in Colorado. 1904, instrument man, Monona-Harrison Co (Iowa) ditch; level rodman with United States Geological Survey in Wyom superintendent Keystone Coal Company at Shelburn, Ind. Appointed engi ing aid in Reclamation Service March 24, 1905.

COLE, D. W., constructing engineer. Born in Georgia, May 10, 1863. cation in home academy. 1884–85, on railroad surveys in New Mexico and rado as axman, chainman, and rodman. 1886–1888, with Burlington Sy as rodman, instrument man, assistant engineer, and resident engineer on veys, construction, and maintenance. 1889, engineer of mines and works Chicago, Wilmington, and Vermilion Coal Company. 1890–91, resident engi in charge heavy construction and track laying for Louisville and Nash Railroad. 1891, on railroad location, Toledo to Chicago. 1892–93, engineer industrial corporations in northern Illinois. 1894–95, resident engineer, sur and construction water-supply system, Waterbury, Conn. 1896–1900, assis engineer on construction, surveys, and studies for metropolitan water boar Massachusetts. 1901–2, resident engineer, construction of dams, reservoir, appurtenances for city of Waterbury, Conn. 1903, principal assistant engi Catskill department, commission on additional water supply, New York 1903–4, on surveys and studies for northern New Jersey flood commis June, 1904, appointed constructing engineer in Reclamation Service.

COMSTOCK, HAROLD DEARBORN, engineering aid. Address, Chelsea, Vt. in Vermont, June 13, 1882. Graduate of Dartmouth College, degree B. S., Thayer School of Civil Engineering, degree C. E. In 1903, rodman, transit and computer on a topographic survey of West Point, N. Y. August 22, 1 appointed engineering aid in Reclamation Service.

CONNER, RALPH M., engineering aid. Address, East Wilton, Me. Bor Maine, March 25, 1878. Graduate of Wilton Academy, Wilton, Me., an University of Maine, degree B. S. in C. E. Measured flow of St. Croix R at Spragues Falls, Me., 1903. 1902, assistant civil engineer, Rumford Power Company. 1903, timekeeper and superintendent for contractor. T in mathematics, University of Maine. June 5, 1904, appointed engineering in the Reclamation Service.

COULTER, WALDO SCARLETTE, assistant engineer. Address, Wyncote, Born, Westboro, Mass., October 12, 1877. Education, common and high sch Member Boston Society of Civil Engineers. 1896–97, with metropolitan w board on surveys and construction of Sudbury reservoir. 1897–98, struct

draftsman. 1898–99, inspector of construction of filtration beds, Clinton, Mass. 1899–1905, with metropolitan water and sewerage board as rodman and instrument man on construction of highways and hydraulic works, Clinton, Mass. Appointed in Reclamation Service April 21, 1905.

COUPE, ALFRED L., engineering aid. Address, Huntley, Mont. Born at Plymouth, Mass., April 7, 1884. Education, Massachusetts Institute of Technology, 1900–1902. 1902, rodman, instrument man, and inspector, Boston and Albany Railroad. Appointed in Reclamation Service March, 1905.

DOERFLING, RICHARD GEORGE, irrigation engineer. Address, Yuma, Ariz. Born in Germany, March 8, 1866. Graduate of Columbian University, B. S. in civil engineering, 1898. Completed course in mechanical engineering of the Scranton Correspondence Schools in 1895. Associate member American Society of Civil Engineers. 1881–1884, apprenticed to county surveyor in Germany. 1884–1886, surveyor and draftsman on railroad location and construction, Harz Mountains. 1886–1889, surveyor and draftsman, North Sea-Baltic Canal. 1889–90, draftsman, street department, St. Louis, Mo. 1890–1894, topographer on upper Missouri River surveys. 1894–1898, draftsman, engineer department, District of Columbia. 1898–99, structural steel draftsman, yards and docks, Navy-Yard, Washington, D. C. 1899–1902, superintendent of construction, United States engineer department, Pittsburg, Pa., on locks, fixed and movable dams, and operating machinery for same. 1902–3, structural engineer, Pacific Rolling Mills, San Francisco, Cal. 1903–4, in private practice. 1904–5, superintendent of construction, twelfth light-house district. Since January 1, 1905, irrigation engineer, Reclamation Service.

DRANE, BRENT SKINNER, engineering aid. Address, Atlanta, Ga. Born, Edenton, N. C., September 9, 1881. Education, University of North Carolina, 1902, A. B. Summer of 1901, with United States Geological Survey on investigation of damages by floods in North Carolina and Tennessee. 1901–2, laboratory assistant, University of North Carolina. 1902–1904, field assistant, United States Geological Survey, in North Carolina, South Carolina, Tennessee, and Virginia. 1904–5, field assistant, United States Geological Survey, in southeastern United States. Appointed in Reclamation Service May 22, 1905.

DUGANNE, CHARLES GEORGE, special disbursing agent. Address, Fallon, Nev. Born, Savannah, Ga., June 18, 1881. Education, common school. Appointed in Reclamation Service March 1, 1905.

EDSON, GORDON, engineering aid. Address, Canadea, N. Y. Born in New York, August 1, 1877. Education, Houghton Seminary, Houghton, N. Y., and Syracuse University, degree C. E., 1904. 1903, chairman and field assistant United States Geological Survey. Five years teacher in public schools of New York. April 1, 1904, appointed engineering aid in Reclamation Service.

ENSIGN, ORVILLE H., electrical expert. Address, Los Angeles, Cal. Born in New York State, July, 1863. Grammar and high school education; two years course in mechanic arts, Cornell. 1883, machine shop, Ithaca, N. Y. 1884–1886, Schenectady Locomotive Works. 1887–88, on construction of isolated plants for Edison Electric Company, New York City. 1889–1893, in charge of test and chief inspector of General Electric Company's factory, Schenectady, N. Y. 1893, moved to California; consulting engineer on test of first three-phase transmission plant in America, at Redlands, Cal. 1894–95, electrical and mechanical engineer Los Angeles and Pasadena Electric Railway and Los Angeles and Santa Monica Railway. 1896–1904, electrical and mechanical engineer of the companies now known as Edison Company of Los Angeles, constructing and operating long-distance hydro-electric plants. Member American Institute

Electrical Engineers. November 1, 1904, appointed electrical expert, Reclamation Service.

FISHER, CASSIUS ASA, assistant geologist. Address, Washington, D. C. Born in Nebraska, February 15, 1872. Received a common school education. In 1889 entered preparatory school at Fremont, Nebr. Entered University of Nebraska, 1893, from which he graduated in 1898. 1896–1901, field assistant, United States Geological Survey, during field seasons. Appointed fellow in geology at University of Nebraska, 1898, and during the following year assistant geologist in the Nebraska State Geological Survey. M. A., University of Nebraska, 1900. 1901–2, field assistant, United States Geological Survey. 1902–3, assistant instructor in geology, Yale University. Author of various publications on geologic subjects. 1903 to date, with Reclamation Service, investigating geology and underground waters in New Mexico, Wyoming, and Colorado.

FISHER, ERNEST JAMES, engineering aid. Address, Browning, Mont. Born, Morris, Minn., August 4, 1879. Education, University of Wisconsin, C. E., 1904. 1901, chainman with location party, Wisconsin. 1902, levelman, United States Geological Survey, in Missouri. 1903, traverseman in Arkansas. 1904–5, under engineer maintenance of way, Great Northern Railroad. May 1, 1905, appointed in Reclamation Service.

FOLLANSBEE, ROBERT, assistant engineer. Address, Ashby Glen, Delaplane, Va. Born in Minnesota, June 7, 1879. Graduated from Cornell University in civil engineering in 1902. 1902–3, engineer with a firm of general contractors of Cleveland, Ohio. 1903, recorder with United States Lake Survey, Detroit, Mich. January–April, 1904, draftsman, United States Geological Survey. April 9, 1904, appointed assistant engineer in Reclamation Service.

FREEMAN, WILLIAM B., engineering aid. Address, Ithaca, N. Y. Born in Montana, September 26, 1883. Graduate Bozeman High School and of Montana Agricultural College, degree B. C. E. 1900, on stream measurements, etc., Montana Experiment Station. 1901, continued same work and also did transit surveying. 1902–3, on stream measurement and seepage work; also worked for United States Geological Survey as level rodman and assistant. 1903, traverseman, United States Geological Survey, July–November. April 9, 1904, appointed engineering aid in Reclamation Service, and assigned to stream-measurement work in Montana.

FRICKSTAD, WALTER NETTLETON, assistant engineer. Address, Leetville, Nev. Born in New York August 17, 1879. Full course in civil engineering, University of California; graduated in 1901, degree B. S. 1901–3, with Southern Pacific Railroad Company, on location, construction, and inspection. 1903–4, assistant engineer for C. A. Warren & Co., on construction of divisions 1 and 2 of main canal, Truckee-Carson project, Nevada. August 26, 1904, appointed engineering aid in Reclamation Service, and January 1, 1905, promoted to assistant engineer.

GORTON, WILLARD L., engineering aid. Address, Chamber of Commerce Building, Denver, Colo. Born in Wisconsin June 13, 1881. Graduate of University of Oklahoma, degree A. B. 1902, tapeman and rodman, Missouri, Kansas and Oklahoma Railroad, on construction and relocation. 1903–4, with Burns & McDonnell, hydraulic engineers, Kansas City, Mo., making preliminary surveys for waterworks and in charge of construction of Chickasha, Ind. T., waterworks and sewerage system. May 8, 1904, appointed engineering aid, Reclamation Service. May–October, 1904, on surveys in connection with Milk River project, Montana. November 8, 1904, transferred to Wyoming. November–December, 1904, in charge of topographic party on Interstate canal, North Platte project. January, 1905, on topography and triangulation, La Plata

project, Colorado–New Mexico. February–March, in Denver office on work connected with the North Platte project.

HALL, ROLLAND SERVIS, engineering aid. Address, Ann Arbor, Mich. Born in Illinois May 19, 1880. Public and high school education; also B. S. in civil engineering, University of Michigan, 1904. August 26, 1904, appointed engineering aid in Reclamation Service.

HAMMOND, GEORGE A., superintendent of borings. Address, Ossining, N. Y. Born in New York State June 23, 1860. 1880–1893, with New York City water supply, making borings for dams and aqueducts. 1894, with American Diamond Drill Company, Virginia. 1894–95, assistant engineer, Ossining Electric Railroad. 1895–96, with New York City water supply. 1896–97, chief engineer, Ossining Electric Railroad Company. 1897–1899, superintendent of borings, United States Deep Waterways Commission. 1900, on drill work in Mexico and California. 1900, superintendent of borings, Erie Canal. 1901, on drill work in British Columbia. 1901–1903, superintendent of borings, Pilleys Island Pyrites Company, Newfoundland. 1903, on Pennsylvania Railroad tunnel, New York City; also Professor Burr commission on additional water supply, New York. 1903–4, drill expert, United States Geological Survey. March 1, 1904, appointed superintendent of borings, Reclamation Service. Inventor of "Hammond" jetting process for sinking casing.

HATCH, LEWIS M., assistant engineer. Address, Denver, Colo. Born at Tacoma, Wash., November 28, 1880. 1902, Washington State College and School of Science, degree B. S. 1902–3, topographer and transitman, Northern Pacific Railway. 1903–4, assistant engineer, maintenance of way, Northern Pacific Railway. August 15, 1904, appointed engineering aid in Reclamation Service and promoted to assistant engineer February 15, 1905.

HAYT, ROBERT OLCOTT, assistant engineer. Address, Huntley, Mont. Born, Corning, N. Y., October 25, 1877. Education, Corning High School; four years in School of Applied Science, Columbia University. 1900–1903, city engineer. 1903–1905, engineer of gas company. April 25, 1905, appointed in Reclamation Service.

HEILEMAN, WILLIAM H., scientist (land classification). Address, Berkeley, Cal. Born, Des Moines, Iowa, October 16, 1869. Education, Iowa State College, B. S. and M. S. Member American Chemical Society, Society of Chemical Industry, London. 1891–1896, assistant chemist, Iowa Experiment Station. 1896–1901, chemist in charge Washington Experiment Station. 1901–2, soil expert, Bureau of Soils, Department of Agriculture. 1902–1905, scientist in charge of alkali reclamation installations, Bureau of Soils. Appointed in Reclamation Service May 10, 1905.

HENNY, DAVID CHRISTIAAN, consulting engineer. Born in Arnhem, Holland, November 15, 1860. Graduate of Government Polytechnic School, Delft, Holland, as civil engineer, 1881. Engaged in reclamation district work and railroad location in Holland, 1881–1884. In railroad construction in Iowa, 1884–85. In waterworks construction in Eastern States, 1885–1887. In railroad construction, Colorado; bridge work, Missouri; tunnel construction, New York, 1887–88. In waterworks construction, Alabama, South Dakota, and Ohio, 1888–89. In general engineering, Colorado and Utah, 1889–1891. Manager Excelsior Wooden Pipe Company, 1892–1902, engaged in construction of wooden stave pipe and general contracting. 1902–1904, general manager Redwood Manufacturers' Company, San Francisco, Cal. Designed and constructed new plant at Black Diamond, Cal., consisting of wharves, yards, tracks, power house, factories, dry kilns, etc. Organized all company's working forces with offices at Black Diamond, San Francisco, and Oakland. 1891–1904, designed and reported on

various waterworks and water-power projects. Consulting engineer West Side and West Los Angeles water companies. Expert for the city of Oakland on waterworks valuation. Member civil-service examination board, engineering department, San Francisco. Two terms president Technical Society Pacific Coast. February 8, 1905, appointed consulting engineer in Reclamation Service.

HORN, FRANK C., constructing engineer. Address, Minidoka, Idaho. Born in Illinois January 8, 1861. Public and high school education. Studied and worked under direction of civil engineer engaged in general practice. 1881, transitman on surveys, and in 1882 assistant engineer on construction, St. Louis and San Francisco Railway Company. 1883, with an engineer in general practice. 1884, transitman and later assistant engineer, Burlington, Cedar Rapids and Northern Railway. 1885–86, principal assistant engineer, Lake, Ill. 1887–1889, chief engineer and superintendent, department of public works, Lake, Ill. 1889–1894, with contracting firms building waterworks, sewerage systems, railroads, buildings, etc. 1894, on track elevation in Chicago for Lake Shore and Michigan Southern Railway and Chicago, Rock Island and Pacific Railway. 1896, in charge of construction of regulating works, Lockport, Ill. 1898–1900, with sanitary district of Chicago, bridge department, on masonry construction. 1900, in charge of construction of water-power plant, Joliet, Ill. 1900–1901, assistant chief engineer on construction of water-power plant, Swan Falls, Idaho. 1901, remodeling and enlarging water-power plant at Kankakee, Ill.; and later in charge of constructing filter beds for Denver Union Water Company, Denver, Colo. 1902–1905, resident engineer in charge of construction of granite masonry dam at Lake Cheesman, Colo. January 17, 1905, appointed constructing engineer in Reclamation Service. Member American Society Civil Engineers.

HOSIG, IRWIN BENJAMIN, hydrographic aid. Address, Sun River, Mont. Born, Hartford, Wis., May 24, 1884. Education, Hartford (Wis.) high school, four years in civil engineering at University of Wisconsin, 1901–1905. Appointed in Reclamation Service May 1, 1905.

HOWE, HENRY A., assistant engineer. Address, Cedar Creek, Montrose County, Colo. Born in Massachusetts, September 2, 1870. Degree S. B. in 1895 from Lawrence Scientific School, Harvard. 1895–1905, with metropolitan water board of Massachusetts, as rodman, instrument man, and assistant engineer. January 12, 1905, appointed assistant engineer in Reclamation Service in charge of Gunnison tunnel alignment and levels, Uncompahgre Valley project, Colorado.

HUBBARD, RAY D., assistant engineer. Address, Klamath Falls, Oreg. Born Brock, Nebr., July 11, 1873. Education, University of Nebraska, 1900, B. S. in C. E. 1900–1902, general civil and mining engineering in South Dakota. 1903, surveyor-general's office, South Dakota. 1903–1904, assistant State engineer of Nebraska. November 12, 1904, appointed assistant engineer in Reclamation Service and assigned to Klamath project.

JOHNSON, LUTHER E., engineering aid. Address, Lawton, Okla. Born in West Virginia, August 10, 1881. Graduate of Missouri University, 1904. 1901–2, rodman and chainman. 1904, drafting and field work during appraisal of town lots, Sulphur, Ind. T. September 10, 1904, appointed engineering aid in Reclamation Service and assigned to duty in Oklahoma.

KEMPTON, GEORGE RUTHERFORD, electrical engineer. Address, Denver, Colo. Born Amenia, N. Y., November 22, 1876. Education, common school, one year Albany high school; two and one-half years Drexel Institute, mechanic arts department; three years Tufts College, graduating in 1900 with degree of B. S. in electrical engineering. 1900–1902, with General Electric Company, Schenec-

tady, N. Y. 1902–1905, electrical engineer, office of Supervising Architect, Treasury Department. June 6, 1905, appointed in Reclamation Service.

KING, CLIFFORD M., engineering aid. Born December 17, 1879. Address, Minidoka, Idaho. Graduated from Western Reserve University, degree A. B., 1901; Cornell University, degree C. E., 1904. Assistant engineer for the Deschutes Irrigation and Power Company, Bend, Oreg., 1904. Draftsman for the Oregon Water Power and Railway Company, Portland, Oreg., 1905. Appointed engineering aid March 7, 1905, in Reclamation Service.

LARSON, ANDREW B., engineering aid. Address, Salt Lake City, Utah. Born, Levan, Utah, November 30, 1872. Education, Agricultural College of Utah, 1894, degree of B. C. E. 1895, chairman on land survey. 1896, rodman for Rio Grande Western Railroad Company; later promoted to levelman on same. Appointed in Reclamation Service May 1, 1905.

LA RUE, EUGENE C., engineering aid. Address, Riverside, Cal. Born in California, November 11, 1879. Graduate of Riverside Grammar School and High School. Graduate of University of California, C. E. June 1, 1904, appointed engineering aid, Reclamation Service.

LEE, WILLIS THOMAS, assistant geologist. Address, United States Geological Survey, Washington, D. C. Born in Pennsylvania, December 24, 1864. Graduate of Wesleyan University, Middletown, Conn., Ph. B. 1894–95, assistant in chemistry and physics, Rhode Island State College. 1895–1898, professor of geology and biology, Denver University. 1898, degree M. S., Wesleyan University. 1898–1900, fellow in geology, Chicago University. 1900–1902, principal of high school, Trinidad, Colo. 1902–3, Johns Hopkins University. Author of various publications on geological subjects. 1903 to date with Reclamation Service, investigating underground waters in Arizona, eastern California, and New Mexico.

LEWIS, SAMUEL JAMES, assistant engineer. Born in New York August 7, 1879. Education, grammar schools and college, New York City, degree B. S. 1902–3, general engineering and stream measurements. 1903, rodman and station assistant, United States Geological Survey. April 11, 1904, appointed hydrographic aid, and on July 1, 1904, promoted to assistant engineer in Reclamation Service.

LIGHTFOOT, WILLIAM J., engineer. Address, North Yakima, Wash. Born in Ohio March 8, 1857. Attended Southeastern Normal School. Took preparatory Latin and Greeek for classical course at Marietta College, Marietta, Ohio. June, 1881, degree B. S., Kansas State Agricultural College, after which some months were spent at Kansas State University. Associate member American Society of Civil Engineers. From 1882 to 1892 in railroad location, construction, and maintenance, most of the time with Atchison, Topeka and Santa Fe Railroad Company. 1892–1899, in private practice and as United States deputy mineral surveyor and mining engineer, Cripple Creek, Colo. 1899–1904, United States examiner of surveys and special disbursing agent, Department of the Interior. June 1, 1904, appointed engineer in Reclamation Service and assigned to duty on Uncompahgre Valley project, Colorado.

LILLIS, BURTON C., assistant engineer. Address, Billings, Mont. Born, Ottawa, Ill., July 27, 1879. Education, Case School of Applied Sciences, 1902, B. S. 1901, on railroad maintenance of way. 1902–3, assistant engineer sewer department, Cleveland, Ohio. 1903–4, aid Coast and Geodetic Survey. Appointed Reclamation Service, June, 1904.

LIND, GEORGE EDMUND, Jr., special disbursing agent. Address, Roosevelt, Ariz. Born, Baltimore, Md., August 3, 1866. Education, common schools, Baltimore City College, Hampden Sydney College, Virginia, and Atlanta Medical

College, M. D. Surgeon in quarantine service, Savannah, Ga. Employed in vital statistics division of Census Bureau. Since 1895 has been connected with the Geological Survey. Appointed in Reclamation Service December 5, 1904.

LYMAN, HENRY LEVIGN, engineering aid. Address, Washington, D. C. Born in Russia, April 14, 1881. Education, Massachusetts Institute of Technology, 1904, B. S. 1901, rodman, Boston, Mass. 1902, plane-table survey in New Hampshire. 1903, rodman and instrument man on Wachusett Aqueduct, metropolitan water board, Clinton, Mass. 1904–5, structural draftsman, Boston, Mass. 1905, draftsman, American Bridge Company, New York, N. Y. Appointed Reclamation Service, March 7, 1905.

LYTEL, JAMES L., assistant engineer. Born in Pennsylvania June 23, 1872. University of Nebraska, degree B. S. 1889–1892, assistant on dam construction and tramways for logging and milling. 1898–99, sergeant, Third Nebraska Volunteer Infantry. 1900–1902, draftsman and topographer in engineering department of military government of Cuba. 1902–1904, with Mexican Central Railway as topographer, transitman, and locating engineer. 1904–5, with United States Reclamation Service, in charge of drafting and designs, Uncompahgre Valley project. March 7, 1905, appointed assistant engineer in Reclamation Service.

MCGEEHAN, PAUL, assistant engineer. Address, Kansas City, Mo. Born in Ohio June 13, 1872. Education, Kansas City High School, Park College, Parkville, Mo., Colorado School of Mines, and Montana School of Mines. 1894, on city surveys, Kansas City. 1895, rodman on railroad location and construction. 1895–1897, topographer. 1897, topographer and assistant locating engineer in southern Illinois. 1897–98, in charge of construction of northern terminals of the Cotton Belt. Engineer officer, United States Army, 1898. In 1899–1900, engineer on railroad location and construction. 1900–1901, with B. & M. Mining Company, Butte, Mont. 1901–2, engineer on railroad location and construction. 1902–3, locating engineer, Orient Railway. April 27, 1904, appointed assistant engineer, Reclamation Service.

MCGREGOR, ROBERT R., engineer. Address, Reno, Nev. Born in California November 26, 1873. Education, Lomper Union High School and University of California. 1899, rodman and instrument man, Southern Pacific Railroad. 1900, transitman with Eldorado Lumber Company; also engineer in charge of railroad location and construction. 1902–3, assistant engineer, Southern Pacific Company, on railroad reconstruction in Nevada. 1903–4, field assistant, Reclamation Service. March 23, 1904, appointed assistant engineer, and on January 1, 1905, promoted to engineer, Truckee-Carson project, Nevada.

MCKINNEY, JOHN M., examiner. Address, Washington, D. C. Born at New York City September 10, 1860. Graduate Washington High School, 1879, and of National University Law School, degree LL. B., 1883, LL. M., 1884. 1880–1884, United States Census. 1884–1905, General Land Office—last ten years on right-of-way work relating to irrigation, railroads, etc. January 26, 1905, transferred to Reclamation Service as examiner.

MAGUIRE, THOMAS FRANCIS JAMES, electrical engineer. Address, Denver, Colo. Born in Massachusetts August 3, 1875. Graduate of Massachusetts Institute of Technology, 1897, degree B. S. in electrical engineering. 1896, rodman with Boston board of survey. 1897–1899, transitman and calculator. 1899–1901, draftsman and calculator with bridge department, city of Boston. 1901–02, electrical engineer, Supervising Architect's Office, Treasury Department. 1902–1904, expert electrical aid, Navy Department. May 16, 1904, transferred to Reclamation Service as electrical engineer.

MAREAN, HERBERT WHEELER, assistant engineer of soils. Address, Washing

ton, D. C. Born in Washington, D. C., December 26, 1878. Education, Colgate University, degree A. B. 1901–1905, assistant in the Soil Survey, United States Department of Agriculture, engaged in field work. Author of various United States Soil Survey reports. April 24, 1905, transferred to Reclamation Service as assistant engineer of soils.

MARTIN, DANIEL GRANT, engineer. Address, Idaho Falls, Idaho. Born in Ohio June 19, 1865. Education, common school, academy at Chetopa, Kans., and Kansas Normal College, Fort Scott, Kans. 1882–1886, teaching school and attending college. 1888–1890, teaching school. 1890–91, with Idaho Falls Canal and Irrigation Company. 1892, engineer and general superintendent Idaho Canal Company. 1893–1897, county surveyor of Bingham County, Idaho. 1893–1896, general engineering practice, city engineer, Idaho Falls, Idaho. 1896, assistant engineer, Idaho Canal Company, on canal construction; engineer on Independent canal, St. Anthony, Idaho, and Marysville canal, Marysville, Idaho. 1897, with Idaho Canal Company, designing and constructing dams, flumes, headworks, etc. 1897–98, superintendent of construction of Marysville canal, Marysville, Idaho. 1898, employed on Idaho canal and Fort Hall Reservation canal; also employed by Independent Canal Company, St. Anthony, Idaho. 1898–99, with Bingham Irrigation and Power Company. 1900–1901, dam and canal work on Pine Creek, Bear River, and Little Lost River, and made the preliminary surveys and estimates for the Twin Falls Land and Water Company in Cassia and Lincoln counties, Idaho; also canal and reservoir reconnaissance surveys on North Fork of Snake River, Idaho. 1902, survey and estimates on canal from Bear River to Chesterfield, Idaho, and general work; also city engineer, Idaho Falls, Idaho. 1903–4, with Twin Falls Land and Water Company; division engineer in charge of construction of dams across Snake River at Milner, Idaho. April 1, 1904, appointed engineer, Reclamation Service, in charge of work on Minidoka project, Idaho.

MARTIN, WILLIAM F., hydrographic aid. Address, Los Angeles, Cal. Born, Attoyac, Tex., January 7, 1878. Education, graduate of University of Texas. One year's graduate study at Cornell, B. S. and C. E. Member Texas Academy of Science. Appointed in Reclamation Service June 14, 1905.

MEANS, THOMAS HERBERT, engineer of soils. Address, Berkeley, Cal. Born in Virginia November 15, 1875. Graduate of Washington, D. C., High School, 1893, scientific course. B. S. in geology, Columbian University, 1898; M. S. in geology, Columbian University, 1901. 1895–1904, with Department of Agriculture in study of western soils and methods of managing irrigated lands. May 6, 1904, appointed engineer of soils in Reclamation Service.

MENDENHALL, WALTER CURRAN, geologist. Address, Washington, D. C. Born in Ohio, February 20, 1871. Education, high school, Portland, Oreg.; B. S., Ohio Normal University, Ada, Ohio; Harvard University; Heidelberg University. 1894–1901, assistant geologist, United States Geological Survey. February 5, 1901, appointed geologist, United States Geological Survey. Author of Geologic section along New and Kanawha rivers (with M. R. Campbell); Reconnaissance from Resurrection Bay to Tanana River, Alaska, 1898; Tertiary granite in Northern Cascades, Washington (with George Otis Smith), 1900; Reconnaissance in the Norton Bay region, Alaska, 1900; Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, 1901; Mineral resources of the Mount Wrangell district, Alaska (with F. C. Schrader), 1903; The Wrangell Mountains, Alaska, 1903; Development of underground waters in the Coastal Plain region of southern California (3 reports); Hydrology of the San Bernardino Valley, California; Geology of the central Copper River region, Alaska, in preparation; also various extracts and short articles.

MINER, JAMES HENRY, assistant engineer. Address, Warrensville, Ohio. Born in Massachusetts, November 24, 1877. Education, University School, Cleveland, Ohio, and Cornell University, degree C. E. Junior member of American Society of Civil Engineers. 1900–1902, with Chicago and Northwestern Railway, tapeman, rodman, and transitman on construction of second track and maintenance of way of Iowa division. 1902–3, with Mason City and Fort Dodge Railroad, transitman on erection of Des Moines River viaduct. 1903, with Norfolk and Western Railway, instrument man on preliminary survey for Lynchburg cut-off. September, 1903, assistant engineer, Page Coal and Coke Company. 1903, with Rock Island system, draftsman in chief engineer's office. 1904, assistant engineer with National Transit Company and Prairie Oil and Gas Company. April, 1904, appointed engineering aid, and November 23, 1904, promoted to assistant engineer in Reclamation Service.

MORRILL, WILBUR N., topographer. Address, New Albany, Ind. Education, Purdue University, 1891, B. C. E. 1891, instrument man Chicago drainage canal. 1892–93, engineer, American Hydraulic Dredging Company, Chicago. 1894 to 1897, general construction of steel bridges and waterworks. 1898, topographer, United States Geological Survey. 1905, transferred to Reclamation Service.

MORSE, HAROLD MARSTON, engineering aid. Address, Washington, D. C. Born in Massachusetts, May 29, 1881. Education, Dartmouth College, B. S.; Thayer School of Civil Engineering, C. E. May 1 to September 1, 1903, assistant engineer on waterworks at Needham, Falmouth, and Lexington, Mass. Appointed engineering aid January 1, 1905.

MORSE, HOWARD SCOTT, assistant engineer. Address, Dedham, Mass. Born in Massachusetts, June 21, 1881. Graduate of Dedham High School and of Massachusetts Institute of Technology, S. B., class of 1903. 1901–2, instrument man in hydraulic and sanitary engineering. 1903, transitman, Pennsylvania Railroad. 1903–4, assistant in civil engineering, Massachusetts Institute of Technology. May, 1904, appointed engineering aid, and November 13, 1904, promoted to assistant engineer in Reclamation Service.

MULFORD, JOHN C., topographic draftsman. Address, Washington, D. C. Born at Winetha, Ill., April 27, 1876. Education, common and high schools of Evanston, Ill.; also drawing course with Scranton Correspondence School. 1904 to 1905, topographic draftsman, Coast and Geodetic Survey. June 16, 1905, transferred to the Reclamation Service.

MURPHY, DANIEL WILLIAM, irrigation engineer. Address, Los Angeles, Cal. Born in Ohio January 18, 1865. Student Indiana University, three years; graduated Stanford University, 1892, degree A. B.; 1893, A. M.; 1896, Ph. D. 1892, student in astronomy at Lick Observatory. 1893–94, instructor in physics, Stanford University. 1894–95, engaged in physical investigations in the Physikalische Technische Reichsanstalt, Berlin, Germany. 1896–1900, assistant professor of physics, Stanford University. Since 1900 continuously engaged in general engineering practice. 1901–2, in charge of work for the drainage of alkali lands and construction engineer for the American Beet Sugar Company. 1903, made topographic survey of the property of the Organita Gold Mining Company. 1903–4, chief engineer in charge of construction of the Santa Cruz, Capitola and Watsonville Railway. 1903, made location and estimates on the proposed extension of the Monterey and Pacific Grove Railway. September, 1904, employed as field assistant in the Reclamation Service. January 14, 1905, appointed irrigation engineer.

PARKER, HORATIO NEWTON, assistant hydrographer. Born in Massachusetts, February 3, 1871. Educated in private and public schools of Cambridge, Mass.,

and at the Massachusetts Institute of Technology. In 1896, appointed assistant biologist, Boston waterworks. After the city waterworks were absorbed by the State of Massachusetts he was appointed biologist and became head of the laboratory. December, 1901, appointed health inspector of Montclair, N. J., which post he left November 9, 1904, when appointed assistant hydrographer, United States Geological Survey.

PATCH, WALTER W., engineer. Address, Belle Fourche, S. Dak. Born in Massachusetts, January 19, 1872. Graduate of Massachusetts Institute of Technology, C. E. Prior to 1894, rodman, Cambridge, Mass.; assistant instructor in surveying at Massachusetts Institute of Technology; principal assistant to city engineer, Rockland, Me.; resident engineer on sewer construction, Camden, Me. 1894, assistant to resident engineer, Boston waterworks. 1895, transitman, Boston waterworks. 1896–1903, assistant engineer, metropolitan waterworks of Massachusetts—one year computing; one year in charge field work and aqueduct gagings for maintenance department; two years principal office assistant in Weston aqueduct department; four years in immediate charge of work on reservoir, dam, and filter-bed construction. 1904, assistant engineer to aqueduct commissioners of New York City. Author of articles printed in Engineering News—"Observations on the use of polar planimeters," April, 1899; "Measurements of the flow of water in the Sudbury and Cochituate aqueducts," June, 1902; "The Marlborough Brook filter beds," April, 1903; "An example of the flattening of cast-iron pipes under earth pressure," December, 1904. February 10, 1905, appointed engineer in Reclamation Service.

PAUL, CARROLL, engineering aid. Address, 2015 Kalorama avenue, Washington, D. C. Born in Tokio, Japan, May 5, 1882. Education, public schools of Washington, D. C.; Dartmouth College, degree B. S.; Thayer School of Civil Engineering, degree C. E. Summer of 1900, rodman, United States Coast and Geodetic Survey. Summer of 1903, engaged as inspector on waterworks construction, Littleton, N. H., and with General Electric Company power and mining department. Summer of 1904, field assistant in Reclamation Service. January 24, 1905, appointed engineering aid in Reclamation Service.

PAUL, CHARLES HOWARD, engineer. Address, Glendive, Mont. Born in Rockport, Mass. Education, high school and Massachusetts Institute of Technology, C. E. course. 1895, rodman, Boston sewer department. 1895–96, with Massachusetts State board of health as rodman, etc. 1896–1900, with metropolitan water board, Boston, as rodman, instrument man, and engineering inspector. 1900–1905, with bureau of filtration, Philadelphia, as draftsman and assistant engineer. March 7, 1905, appointed engineer in the Reclamation Service.

PRATT, R. WINTHROP, assistant engineer. Address, Columbus, Ohio. Born in Massachusetts, December 21, 1876. Graduate of Agassiz Grammar School and English High School, Boston; Massachusetts Institute of Technology, degree S. B. In 1896, rodman, city engineer's department, Boston, Mass. 1898, assistant in engineering department, Massachusetts State board of health. 1898–99, with Boston and Albany Railroad, rodman and instrument man. 1899–1903, assistant engineer in engineering department, Massachusetts State board of health. 1903–4, engineer to the Ohio State board of health and at the same time in charge of stream measurements in Ohio for United States Geological Survey. March 28, 1904, appointed assistant engineer, Reclamation Service.

PRENDERGAST, FREDERIC F., assistant engineer. Address, Great Falls, Mont. Born in Nebraska, July 1, 1878. High school graduate, and attended College of Civil Engineering, University of California. In 1897–1899, chainman and rodman on canal and railroad work in southern California. 1901, transitman on construction of wooden-stave pipe line. 1902–3, transitman on railroad location.

1903, engineer in charge of construction of deep-water wharf and trestle, San Francisco Bay; also in charge of steam-shovel work on railroad construction. 1904, field assistant with United States Reclamation Service on Milk River project, Montana. November 25, 1904, appointed assistant engineer Reclamation Service.

PRINCE, JOHN R., topographic draftsman. Address, Los Angeles, Cal. Education, public schools and Malvern College, England. 1883–1889, draftsman, ordnance survey of Great Britain; also, same year, with Julius Blen & Co., New York. 1890–1901, general engineering assistant and draftsman, with C. C. Vermeule, New York, and draftsman to Geological Survey of New Jersey. 1901, topographic draftsman, with United States Board of Engineers, War Department, New York City. 1902–3, draftsman and chief draftsman, city engineer department, Los Angeles, Cal. 1903–1905, draftsman, United States Geological Survey. January 21, 1905, appointed topographic draftsman in Reclamation Service.

PYLE, FRED D., engineering aid. Address, Mitchell, Nebr. Born in Pennsylvania October 8, 1882. Education, Utah Agricultural College, 1903, B. S. in C. E. 1903, rodman and levelman, United States Geological Survey in Utah. 1904, private engineering and assistant to engineer at Utah Experiment Station. 1904, field assistant, United States Geological Survey, Utah. 1905, private engineering work in western Wyoming. May 1, 1905, appointed engineering aid in Reclamation Service.

REABURN, DE WITT LEE, topographer. Address, Klamath Falls, Oreg. Born West Virginia, 1871. Education, University of Illinois and University of Wisconsin. Associate member American Society of Civil Engineers. 1891–1893, on land, town-subdivision, and railroad surveys in Virginia; also with American Bridge Company, Roanoke, Va., on bridge erection. 1893–1897, with Mississippi River Commission engaged in topographic, hydraulic, and triangulation work. 1897–1905, topographer with United States Geological Survey. April 1, 1905, transferred to Reclamation Service and assigned to the Klamath project.

RHEAD, JOSIAH LEWIS, assistant engineer. Born in Utah, May 8, 1868. Education, Agricultural College of Utah, B. S. in civil engineering. From June to December, 1896, assistant in stream measurements and calculations of canals and rivers of Cache Valley, Utah. From 1896 to 1900 acted as assistant engineer and engineer on Bear River canal, Utah, for Bear River Irrigation and Ogden Water Works Company, Ogden and Corrine, Utah. July–October, 1900, assistant engineer on West Gallatin Irrigation Company's canal, in Gallatin Valley, Montana. 1901–2, superintendent and engineer of the Big ditch in Yellowstone County, Mont. 1902–3, with United States Geological Survey in triangulation and leveling in Montana. May 1, 1903, appointed assistant engineer in the Reclamation Service.

RICHARDSON, GEORGE BURR, assistant geologist. Address, Washington, D. C. Born in New York, August 21, 1872. Graduate of Harvard University, S. B., 1895. Johns Hopkins University, Ph. D., 1901. In 1896, geologic field assistant, United States Geological Survey, Richmond basin, Virginia; 1897, same, in Indian Territory. 1898, surveyor and geologist, Cassiar Central Railway Company, British Columbia. 1899, geologic field assistant, United States Geological Survey, Black Hills, South Dakota. Since 1900, assistant geologist, United States Geological Survey, working in Alaska, Pennsylvania, California, Utah, and Texas.

ROBERTS, JOHN MILTON, assistant engineer. Address, Montrose, Colo. Born, Lincoln, Nebr., October 3, 1873. Education, common school and three years in University of Nebraska. 1888, assistant to engineering architect. 1899–1900,

ıstructed Roberts ditch, near Paonia, Colo. 1901, repaired breaks in canal · Overland Ditch Company. 1903, in charge of field party, United States ological Survey, at Montrose, Colo. 1904, under W. M. Reed in New Mexico.)4–5, surveys of reservoir sites in Colorado under A. L. Fellows. 1905, in arge of construction of Montrose, Colo., waterworks.

ROTHI, PAUL, engineering aid. Address, Mitchell, Nebr. Born, Moland, nn., December 14, 1877. Education, high school and University of Minnesota, E. Summers of 1900, 1901, 1902, and 1903, railroad surveys; 1904–5, struc-ral draftsman. Appointed in Reclamation Service May 4, 1905.

RUSSELL, WALTER S., engineer. Address, Fallon, Nev. Born in Wisconsin, tober 27, 1863. Education, high school and private study. 1887–1889, rod-ın, levelman, and transitman, on railroad work. 1890, levelman and transit-ın, Pamo Water Company, San Diego, Cal. 1891, chief of party for irrigation ıtrict, San Diego, Cal., also chief of party for Bear Valley Irrigation Company.)2, locating engineer for Mount Tecarte Water Company, San Diego County.)3, office practice, San Diego, Cal. 1894–1898, engineer, Southern California ›untain Water Company. 1899, surveyed and reported on water power for draulic mining claims in Utah and Arizona. 1900, office practice, Spokane, ısh. 1901–2, with California Construction Company, superintendent of con-uction of tunnel for Power Development Company at Bakersfield, Cal. 1902–3, th Atlantic, Gulf and Pacific Company, superintendent of construction of dry :k for the United States at Mare Island, Cal. 1903, engineer for E. B. & A. L. ›ne Company, general contractors. March 19, 1904, appointed engineer in clamation Service.

SANFORD, GEORGE OTIS, assistant engineer. Address, Westboro, Mass. Born in ockton, Mass. Education, civil engineering course at Worcester Polytechnic stitute, class of 1895. In summer of 1892 in city engineer's office, sewer partment, Brockton, Mass. From August, 1895, to March, 1905, with metro-litan water and sewerage board at Clinton, Mass.; as rodman and instrument ın on triangulation, topographic surveying, land surveying, construction of ıds, railroads, and reservoirs. Assistant engineer on the construction of the rd division of the Weston aqueduct and the south dike of the Wachusett ıervoir. March 1, 1905, appointed assistant engineer in the Reclamation rvice.

SARGENT, RALPH S., engineering aid. Address, Berkeley, Cal. Born in Michi-n, November 25, 1880. University of California, civil engineering course.)3, rodman and transitman on topography. Summer of 1904, rodman and ·elman on a stadia survey on the Kaweah River. Winter of 1904, mine sur-ying in Amador County, Cal. April 27, 1904, appointed engineering aid in the clamation Service, and assigned to duty on the Boise-Payette project, Idaho.

SEIDEMANN, HENRY P., special disbursing agent. Address, Belle Fourche, Dak. Born in Texas, April 4, 1883; education, public schools and business lege. 1899–1902, office assistant in pay department of the army at San an, P. R. 1902–1905, messenger, clerk, and bookkeeper in United States ological Survey. May 10, 1905, promoted to special disbursing agent in the clamation Service.

SHELEY, HORACE W., engineering aid. Address, Salt Lake City, Utah. Born Missouri, April 29, 1880. Educated in public schools of Texas and Missouri. tended Westminster College, Missouri, 1894–1897, and University of Utah)7–1901. 1901, studied and assisted mining engineers and experts in Tintic ning district. 1901–2, with Rio Grande Western Railway. January to June,)3, student. 1903–4, field draftsman, computer, and topographer in Reclama-n Service. December 23, 1904, appointed engineering aid.

SHINBUR, ELVER L., assistant engineer. Address, Wyncote, Wyo. Born, Oakland, Nebr., April 3, 1879. Education, University of Nebraska, B. S. in C. E. 1900, rodman and chainman on railroad in Colorado and Montana. 1901, instrument man and inspector on viaduct construction, Nebraska. 1901–2, with United States military government in Cuba as topographer. 1902–3, assistant engineer in charge of location and construction, Insular Railway Company, Habana. 1903–4, resident engineer on construction of railroad, Mexico. 1904–5, in charge of field parties on irrigation investigations in Colorado and New Mexico. March 7, 1905, appointed in Reclamation Service. Now resident engineer in charge of division 2, interstate canal, North Platte project.

SHIPMAN, CHARLEY E., engineering aid. Address, Great Falls, Mont. Born at West Liberty, Iowa, November 16, 1882. Graduated from West Liberty High School and from Iowa State College, civil engineering department. Paving inspector, Cedar Falls, Iowa, summer of 1903. Draftsman with American Bridge Company, Ambridge, Pa., for six months. March 7, 1905, appointed engineering aid in the Reclamation Service.

SIEBENTHAL, CLAUDE ELLSWORTH, assistant geologist. Address, Bloomington, Ind. Born in Indiana, April 16, 1869. Stanford University, A. B. in 1892 and A. M. in 1893. Fellow in geology, University of Chicago, 1897–1899, 1900–1901. Instructor of physiography, high school, Indianapolis, Ind., 1899–1900. 1889–1893, assistant and assistant geologist, Geological Survey of Arkansas. 1896–1898, assistant geologist, Geological Survey of Indiana. In 1901 appointed assistant geologist, United States Geological Survey. Now on work in western section, division of hydrology.

SIMPSON, PAUL DYER, engineering aid. Address, Chamber of Commerce Buiding, Denver, Colo. Born in Nebraska, March 10, 1876. B. S. in civil engineering, University of Maine. Eight years in general engineering work, including land surveying, highway location and construction, waterworks, sewer, and masonry construction, city, tunnel, and railroad work, and hydrographic and topographic surveying and drafting. With United States Army during Spanish-American war. Tutor in civil engineering, University of Maine. September 29, 1904, appointed engineering aid in Reclamation Service, and assigned to duty in western Nebraska, Wyoming, and Colorado.

SLOAN, JAMES HARVEY, engineering aid. Address, Browning, Mont. Born, Bozeman, Mont., April 10, 1881. Education, Bozeman High School; Montana Agricultural College, 1903, B. C. E. Summer of 1904, field assistant to L. E. Granke on Milk River project. Appointed in Reclamation Service April 28, 1905.

SMITH, CHESTER WASON, constructing engineer. Address, Roosevelt, Ariz. Born in New Hampshire, February 21, 1866. April, 1888, to June, 1892, with Aspinwall & Lincoln, Boston, Mass., in miscellaneous private practice. June, 1892, to August, 1893, assistant to city engineer, Marlboro, Mass., on sewer and waterworks construction. August, 1893, to August, 1895, with Massachusetts State board of health on preliminary surveys and estimates for an additional water supply for the metropolitan district. August, 1895, to December, 1904, assistant engineer and division engineer for metropolitan water board and metropolitan water and sewerage board on construction of works for additional water supply. 1901 to December, 1904, division engineer in charge of construction of Wachusett dam; during 1904 also chief inspector on same. December 16, 1904, appointed construction engineer in Reclamation Service.

SOPER, RALPH C., engineering aid. Address, Washington, D. C. Born, South Royalton, Vt., February 3, 1881. Education, Dartmouth College, 1902, A. B.; Thayer School of Civil Engineering, 1904, C. E. 1903, assistant on railroad

survey. 1904–5, with Illinois Steel Company. Appointed in Reclamation Service May 1, 1905.

SPALDING, WALTER J., engineering aid. Address, Salt Lake City, Utah. Graduate of Missouri University, degree of B. S. in C. E. Summer of 1903, levelman and transitman on proposed St. Louis and St. Paul Railroad. 1904, student assistant in surveying, having charge of parties in the field and examining and grading papers. August 24, 1904, appointed engineering aid in Reclamation Service. Junior member American Society Civil Engineers.

STEERE, ANTHONY ENOCH, engineering aid. Address, Minidoka, Idaho. Born, Scranton, Iowa, January 22, 1882. Rhode Island College, B. S., mechanical engineering, 1900. 1901–2, student civil engineering, Rhode Island College. 1902–1904, with metropolitan water and sewerage board, Boston, Mass. Appointed in Reclamation Service, June, 1904.

STILES, ALBERT IRVINE, engineering aid. Address, Washington, D. C. Born in Pennsylvania, October 1, 1883. Education, Washington, D. C., high schools; civil-engineering course at Stanford University. 1900–1902, chainman, computer, and draftsman, General Land Office. 1903–4, aid, Coast and Geodetic Survey, on surveys in Alaska. April 25, 1904, appointed engineering aid, Reclamation Service. Levelman and transitman, Utah Lake project.

STONE, CHARLES HENRY HOWARD, assistant analyst. Born in Massachusetts, September 11, 1876. Educated in Newton public schools. Entered Massachusetts Institute of Technology in 1892; graduated in 1896, chemical course, degree B. S. 1897, in charge of chemical laboratories at Rhode Island State College of Agriculture and Mechanic Arts. 1897–1900, chemist with Massachusetts State board of health. 1900–1905, assistant State gas inspector of Massachusetts. January 16, 1905, appointed assistant analyst in Reclamation Service.

STROEBE, GEORGE G., engineering aid. Address, Mandan, N. Dak. Born Ferrysburg, Mich., October 11, 1877. Education, Chicago University, University of Wisconsin, C. E. Instructor descriptive geometry and drawing, University of Wisconsin, 1904–5. May 2, 1905, appointed in Reclamation Service.

STUBBLEFIELD, GARFIELD, engineering aid. Address Exeter, Mo. Born in Missouri, July 18, 1878. Graduate of University of Arkansas, and attended Cornell University civil-engineering course. Summers of 1900, 1901, and 1902, levelman, topographer, and draftsman. 1902–3, instructor in civil engineering at University of Arkansas. 1903, levelman, United States Geological Survey. September 1, 1904, appointed engineering aid in Reclamation Service.

SWENDSEN, WARREN G., engineering aid. Address, Box S, Salt Lake City, Utah. Born in Utah, July 26, 1880. B. S. in civil engineering, Agricultural College of Utah, 1904. Summer of 1901, employed at Utah experiment station. Summer of 1902, transitman and levelman on survey of Cub River reservoir site and proposed aqueduct, and later in reconnaissance party, United States Geological Survey. Summer of 1903, assistant to resident engineer, Glennsferry Land and Irrigation Company. 1904, with Reclamation Service, gaging streams and on reconnaissance work as transitman and levelman. December 19, 1904, appointed engineering aid.

TABOR, ERNEST F., engineer. Address, U. S. Geol. Survey, Cody, Wyo. Born February 26, 1866. Graduate of grammar school: attended high school and University of California. 1887–1889, computer and assistant, San Diego Flume Company. 1890, preliminary surveys for irrigation works for the Escondido irrigation district, and 1894–95, in charge construction of same. 1891, on resurvey of subdivision of Rancho Rincon del Diablo. 1892–93, assistant engineer, Bear Valley Irrigation Company. 1895–96, location and construc-

LIST OF TECHNICAL PAPERS BY MEMBERS OF RECLAMATION SERVICE.

The following is a partial list of papers relating to irrigation and irrigation engineering heretofore prepared by engineers and other employees of the Reclamation Service and published either in book form or in technical periodicals. Only the most important of those relating to irrigation or irrigation engineering are included, and many minor papers have been omitted.

BABB, CYRUS C., engineer.

Hydrograhpy of the Potomac Basin: Trans. Am. Soc. Civil Eng., vol. 27, 1892, pp. 21–33.

Discussion on Black Eagle Falls Dam, Montana: Trans. Am. Soc. Civil Eng. vol. 27, 1892, p. 67.

Rainfall and River Flow: Trans. Am. Soc. Civil Eng., vol. 28, 1893, pp. 323–337.

Surveys and Examinations of Uinta Indian Reservation: House Doc. No. 671, 57th Cong., 1st sess., 1902.

BENNETT, S. G., engineer (with J. B. Lippincott).

Relation of Rainfall to Run-off in California: Eng. News, vol. 47, No. 23, p. 467.

BIEN, MORRIS, supervising engineer.

Right of Way on Public Lands for Irrigation Power and Railroad Purposes: Circulars General Land Office, 1894–1901.

Grants of Rights of Way over Public Lands: Ann. Repts. General Land Office, 1893–1902.

Right of Way upon the Public Lands: Proc. Third Irr. Cong., Denver, 1894.

Relation of Federal and State Laws to Irrigation: Proc. Eleventh Irr. Cong., Ogden, 1903, and Water-Sup. and Irr. Paper No. 93, U. S. Geol. Survey, 1904.

Draft of a State Irrigation Code, 1904.

Discussion of a Draft of an Irrigation Code: Proc. Twelfth Irr. Cong., El Paso, 1904.

CHANDLER, ALBERT E., engineer.

Water Storage on Cache Creek, California: Water-Sup. and Irr. Paper No. 45, U. S. Geol. Survey, 1901.

Duty of Water in Tule River Basin, California: Report of Irr. Investigations for 1901, Office of Experiment Stations, Bull. No. 119, Washington, 1902.

Irrigation Development in Nevada: Proc. Nevada Acad. Sci., vol. 1, No. 1, Reno, Nev., 1904.

CHANDLER, E. F., assistant engineer.

Irrigation in North Dakota: Bull. Univ. North Dakota, October, 1904.

Methods of Stream Measurement: Third Bien. Rept. North Dakota State Geol. Survey.

River Systems of North Dakota: First Bien. Rept. North Dakota State Engineer.

DOERFLING, RICHARD G., irrigation engineer.

Ueber Wasserbau im allgemeinen und Stauanlagen im besonderen: Technologist, vol. 6, No. 3, 1900.

DRANE, BRENT SKINNER, engineering aid.

Collection of Data from Vertical Velocities Observations in Southeastern Rivers: Water-Sup. and Irr. Paper No. 95, U. S. Geol. Survey, 1904., pp. 139–150.

Report on the Destructive Flood of June 6, 1903, near Spartanburg, S. C.: Water-Sup. and Irr. Paper No. 96, U. S. Geol. Survey, 1904, pp. 13–19.

DUBYEE, EDWARD, cement expert.

Comparison of Standard Specifications for Testing Portland Cement: Eng. News, 1900.

Cement: Water-Sup. and Irr. Paper No. 33, U. S. Geol. Survey, 1900, pp. 82–90.

Refractory Linings for Portland Cement Kilns: Eng. Record, 1900.

The First Manufacture of Portland Cement by Direct Process in Rotary Kilns: Eng. News.

ELLOWS, A. L., engineer.

Water Resources of the State of Colorado: Water-Sup. and Irr. Paper No. 74, U. S. Geol. Survey, 1902.

Measurement of Water: Irr. Bull. No. 1, Office State Engineer of Colorado.

The Gunnison Tunnel: Forestry and Irr., November, 1902.

IELD, JOHN E., engineer.

Irrigation from Big Thompson River: Bull. No. 118, U. S. Dept. Agriculture, 1902.

ITCH, CHARLES H., engineer.

Land Classification in Sonora Quadrangle, California: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 5, 1900, pp. 569–571.

Land Classification in Yosemite Quadrangle, California: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 5, 1900, pp. 571–574.

Woodland of Indian Territory: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 5, 1900, pp. 603–662.

ALL, BENJAMIN H., consulting engineer.

Hydraulic Excavation: Eng. Soc. Ann., Univ. Georgia, 1894.

Plans for Irrigation of Rio Grande Valley in New Mexico, Texas, and Mexico: Third Ann. Rept. U. S. Reclamation Service.

AMLIN, HOMER, engineer.

Water Resources of Salinas Valley, California: Water-Sup. and Irr. Paper No. 89, U. S. Geol. Survey, 1904.

Underground Tests in the Drainage Basin of Los Angeles River: Water-Sup. and Irr. Paper No. 112, U. S. Geol. Survey, 1904.

ANNA, F. W., assistant engineer.

Parabolic Method of Computing Stream Gagings: Eng. News, February 9, 1905.

River Discharge, Mean Velocity and Cross-Sectional Area Curves: Eng. News, March 23, 1905.

ARDESTY, W. P., assistant engineer.

The Swan Lake Reservoir and Canal System, Utah: Eng. News, August 29, 1895.

The Bear River Irrigation System, Utah: Eng. News, February 6 and 13, 1896.

The Twin Lakes Reservoir, Colorado: Eng. News, June 30, 1898.

The Montrose Irrigation Canal, Colorado: Eng. News, March 23, 1899.

The Utilization of Utah Lake as a Storage Reservoir: Eng. News, May 21, 1903.

HENNY, D. C., consulting engineer.

Water Pipe Built of Wooden Staves: Trans. Tech. Soc. Pac. Coast, March, 1892.

Effect of Curves in Pressure Pipes upon the Required Support: Trans. Tech. Soc. Pac. Coast, November, 1893.

Discussions of Flow of Water: Trans. Am. Soc. Civil Eng., July, 1898, and November, 1900.

Wooden-Stave Pipes *v.* Riveted-Steel Pipes: Jour. Assoc. Eng. Socs., November, 1898.

Discussion on Stave Pipe, with Records of Original Experiments: Trans. Am. Soc. Civil Eng., June, 1898.

HORTON, ROBERT E., hydrographer.

The Indian River Dam: Eng. News, May 18, 1899 (with George W. Rafter and Wallace Greenalch).

Discussion on Flow of Water over Dams: Trans. Am. Soc. Civil Eng., 1900, vol. 44, pp. 340–345.

Backwater and Flowage: Trans. Michigan Eng. Soc., 1902, pp. 49–57.

Weir Experiments, Coefficients, and Formulas (in preparation as a Water-Sup. and Irr. Paper, U. S. Geol. Survey).

HOYT, JOHN C., engineer.

Methods of Measurement of the Flow of Streams: Eng. News, January 14, 1904.

Methods of Estimating Stream Flow: Eng. News, August 4, 1904.

Distribution of Velocity in Stream Flow: Eng. News, January 12, 1905.

Hydrographic Manual of U. S. Geol. Survey: Water-Sup. and Irr. Paper No. 94, U. S. Geol. Survey, 1904 (with Edward C. Murphy and George B. Hollister).

LEE, WILLIS T., assistant geologist.

Underground Waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

Underground Waters of Salt River Valley, Arizona (in preparation for publication by U. S. Geol. Survey).

Underground Waters of Owens Valley, California (in preparation for publication by U. S. Geol. Survey).

LIPPINCOTT, JOSEPH B., supervising engineer.

Storage of Water on Gila River, Arizona: Water-Sup. and Irr. Paper No. 33, U. S. Geol. Survey.

Storage of Water on Kings River, California: Water-Sup. and Irr. Paper No. 58, U. S. Geol. Survey.

Development and Application of Water in Southern California: Water-Sup. and Irr. Papers Nos. 59 and 60, U. S. Geol. Survey.

California Hydrography: Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey.

Water Supply in San Bernardino Valley, California: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, pp. 540–629.

Yuma Project: Out West, June, 1904.

Relation of Forest Cover to Stream Flow: Read at El Paso Irr. Cong.

MATTHES, GERARD H., engineer.

Dikes of Holland: Nat. Geog. Mag., June, 1901.

MEANS, THOMAS H., engineer of soils.

Alkali Soils of Yellowstone Valley: Div. of Soils Bull. 141, Dept. of Agriculture.

Soil Survey in the Pecos Valley, New Mexico: Field Operations Div. Soils, Dept. of Agriculture, 1899.

MEANS, THOMAS H.—Continued.

Soil Survey in Salt River Valley, Arizona: Field Operations Div. Soils, Dept. of Agriculture, 1900; also published as Ariz. Exp. Sta. Bull. No. 41.

Soil Survey around Fresno, Cal.: Field Operations Bureau Soils, Dept. of Agriculture, 1900.

Reclamation of Alkali Lands in Egypt: Bull. 21, Bureau Soils, Dept. of Agriculture.

Soil Survey around Imperial, Cal.: Field Operations Bureau Soils, 1901; also published as Circular 9, Bureau Soils, Dept. of Agriculture.

Crops Grown on Alkali Lands in Egypt: Yearbook, U. S. Dept Agriculture, 1902 (with Thos. H. Kearney).

Use of Alkali Waters in Irrigation: Circular 10, Bureau Soils, Dept. of Agriculture; also Water-Sup. and Irr. Paper No. 93, U. S. Geol. Survey.

Reclamation of Alkali Lands at Fresno, Cal.: Circular 11, Bureau Soils, Dept. of Agriculture.

MURPHY, E. C., engineer.

Hydrographic Manual: Water-Sup. and Irr. Paper No. 94, U. S. Geol. Survey, 1904 (with John C. Hoyt and George B. Hollister).

Accuracy of Stream Measurements: Water-Sup. and Irr. Paper No. 95, U. S. Geol. Survey, 1904.

Method of Computing Daily and Monthly Discharge of Streams of Sandy, Changeable Bed: Eng. News, April 21, 1904.

Seven-Year Periodicity in Rainfall: Proc. Kans. Acad. Sci., vol. 13.

Increase of Rainfall in Kansas: Proc. Kans. Acad. Sci., vol. 14.

Irrigation along the Arkansas in Western Kansas: Kans. Univ. Quart., vol. 3, p. 117.

Collection and Storage of Water in Kansas: Kans. Univ. Quart., vol. 3, p. 217.

Notes on Discharge of Kansas River at Lawrence, Kans.: Kans. Univ. Quart., vol. 4, p. 163.

Windmills for Irrigation: Water-Sup. and Irr. Paper No. 8, U. S. Geol. Survey.

Windmill: its Efficiency and Economic Use: Water-Sup. and Irr. Papers Nos. 41 and 42, U. S. Geol. Survey.

Current Meter and Weir Discharge Comparisons: Trans. Am. Soc. Civil Eng., vol. 47, p. 370.

NEWELL, FREDERICK HAYNES, chief engineer.

Permeability of Sand Rock: Eng. and Min. Jour., vol. 40, 1885, p. 79.

Methods of Deep Drilling: Proc. Soc. Arts, Mass. Inst. Tech., 1885–86, p. 53.

Drilling and Care of Oil Wells: Rept. Geol. Survey of Ohio, vol. 6, 1888, pp. 476–515.

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Correspondence should be addressed to

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DESTRUCTIVE FLOODS IN THE UNITED STATES IN 1904

BY

EDWARD CHARLES MURPHY
AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., April 10, 1905.

SIR: I transmit herewith a manuscript, prepared by E. C. Murphy, entitled "Destructive Floods in the United States in 1904," and request that it be published as a water-supply paper.

The value of property along the streams of this country is rapidly increasing and data on the flood flow of streams and means of preventing overflow are of increasing interest and value.

Data on the other extreme of stream flow are also of increasing interest and value, as droughts affect not only the agriculture and navigation interests of the country, but also, to a considerable extent, its manufacturing and transportation interests.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

DESTRUCTIVE FLOODS IN THE UNITED STATES IN 1904.

By E. C. Murphy and others.

INTRODUCTION.

Destructive floods occurred on several streams of the United States during the year 1904, mainly on the smaller streams in the western part of the country. The loss of property caused by these floods, while large in the aggregate, is small compared with flood losses of some previous years.

The first in chronologic order in the list of destructive floods of 1904 is that on Sacramento River in California, which occurred in February and which was the most destructive in the records of that stream. In March occurred the flood on Susquehanna River, due mainly to ice gorges; the flood of Mohawk River in New York and that of Grand River in Michigan, due mainly to the rapid melting of snow; and the flood on Wabash River, due mainly to rainfall. In May very heavy rains in northern Colorado and southern Wyoming caused a flood on Cache la Poudre River and Crow Creek, which resulted in the loss of considerable property along them. In the early part of June the Belle Fourche and other streams on the northern slope of the Black Hills were in destructive flood. In the latter part of June and the early part of July continued heavy rain caused the rivers in southeastern Kansas to be higher than ever known before and to cause much damage. Several cloud-bursts occurred in this month, causing local floods in western Pennsylvania and western Arizona. The Johnstown, Pa., and the Troxton Canyon, Arizona, floods are examples of these. Very heavy precipitation during the latter part of September and the early part of October in southern Colorado, New Mexico, and Texas caused floods of unprecedented magnitude on Purgatory, Canadian, Pecos, and other streams of that region.

After these floods in the western part of the country there was a severe drought in the eastern part. This was felt most keenly in the upper part of the Ohio drainage basin and to a lesser extent in the Southern and New England States. This drought is briefly described in this paper.

The United States Geological Survey has carried on a study of the water resources of the country for the past seventeen years, and there is now available for the use of engineers and others interested a large mass of data bearing on the seasonal flow of the principal streams of the country. In this paper that part of these data which bears on the maximum rate of run-off of streams is brought together and a method is given for the determination of the waterway area of streams.

The writer acknowledges his indebtedness for data used in the preparation of this paper to Mr. F. H. Newell, chief engineer of the Reclamation Service and hydrographer in charge of stream-gaging work; Messrs. J. B. Lippincott, B. M. Hall, A. L. Fellows, M. C. Hinderlider, W. M. Reed, G. H. Matthes, and R. E. Horton, in charge of the districts in which the floods described in this paper have occurred; and especially to S. G. Bennett, Raymond F. Walter, F. W. Hanna, J. C. Hoyt, James A. Armstrong, A. J. Parshall, R. I. Meeker, George B. Monk, W. G. Russell, Frank S. Dobson, and T. Tobish.

SACRAMENTO RIVER FLOOD, CALIFORNIA.[a]

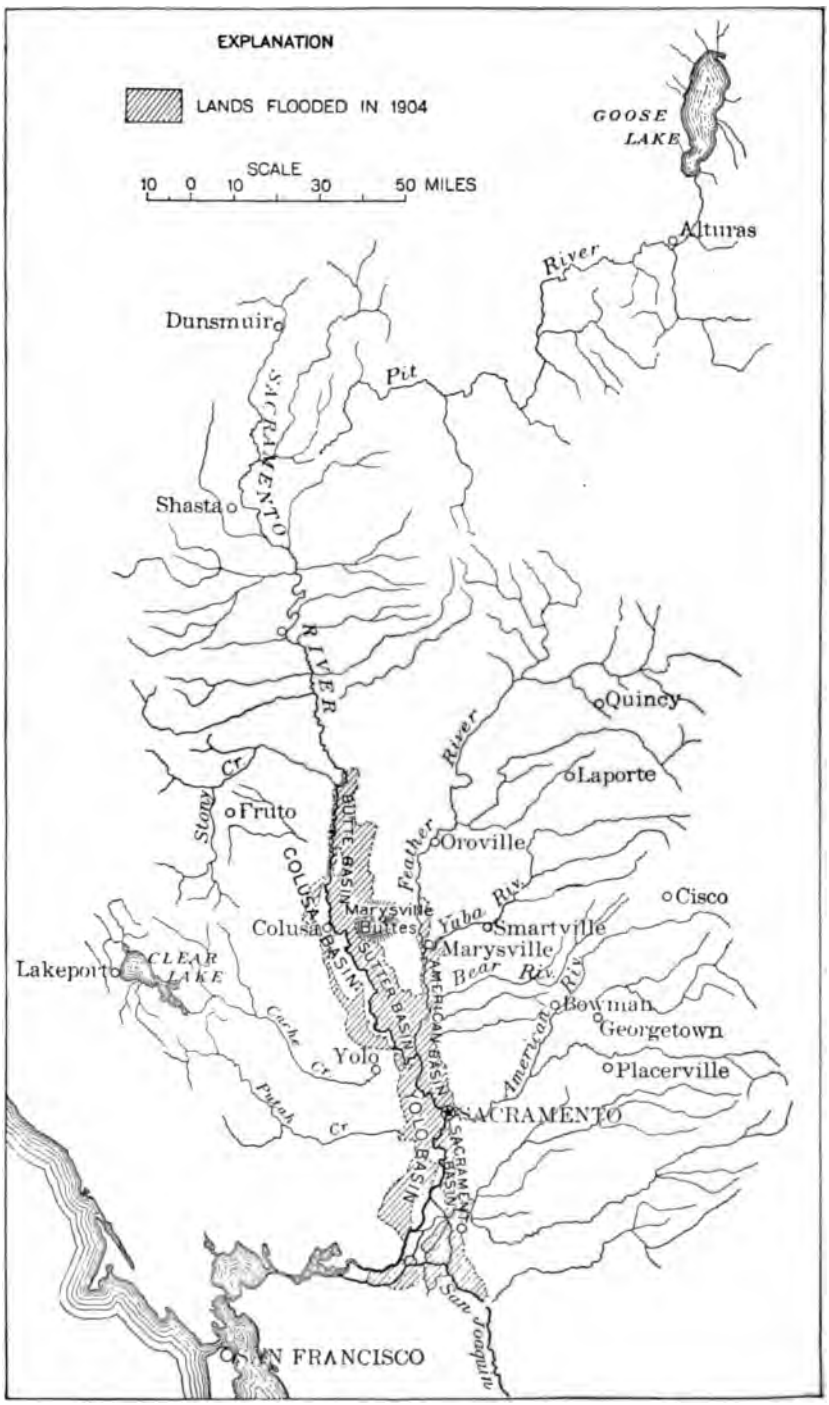
From February 15 to the end of March, 1904, occurred the most destructive flood, as far as property was concerned, in the recorded history of Sacramento. The greatest known flood occurred forty-odd years before, in January, 1862, and was due to rainfall, the precipitation in December, 1861, and January, 1862, just prior to it having been 23.62 inches. This flood filled the entire flood plain, and was not limited, as was the later one, by the reclamation of large tracts of bottom land, nor was the channel below the mouth of Feather River then filled with mining débris as it is now.

STREAMS AND DRAINAGE BASIN.

Sacramento River rises in the northern part of California, flows in a general southerly direction for about 260 miles and empties into Suisun Bay. Its chief tributaries are Pitt, McCloud, Feather, and American rivers, entering from the east, and Cache, Putah, and Stony creeks, entering from the west. These streams and the location of the gaging and precipitation stations in this basin are shown in Pl. I.

Between the Sierra Nevada and the Coast Range of mountains lies what is called the Great Valley of California, having a length of about 400 miles and a width varying from a few miles to 80 miles, the average width being 40 miles. It has a gentle slope, being practically an unbroken plain, with an area of about 15,700 square miles.

[a] Prepared from report of S. G. Bennett, engineer.



DRAINAGE BASIN OF SACRAMENTO RIVER.

The northern portion of this valley is drained by the Sacramento; the southern part by the San Joaquin River.

What is commonly known as Sacramento Valley extends only as far north as Iron Canyon, 4 miles beyond Red Bluff. The part of the drainage basin above this canyon is very different in topography from that below it, being mainly hilly and mountainous, with steep slopes and rapid run-off, while the valley below this canyon has a remarkably uniform slope. At Red Bluff the elevation is about 300 feet above sea level, near Colusa it is 50 feet above sea level, and at Sacramento it is 11 feet—that is, from Red Bluff to Colusa there is a fall of 250 feet in 65 miles, and from Colusa to Sacramento there is a fall of 39 feet in 50 miles. The area of Sacramento Valley is about 4,250 square miles, 2,510 square miles being high plains or hilly land, not subject to overflow, 450 square miles subject to occasional overflow, 1,254 square miles naturally subject to overflow, and 38 square miles constituting the surfaces of perennial streams.

Sacramento Valley below the mouth of Stony Creek is a typical flood plain, the river banks being from 5 to 20 feet higher than the land on either side of the channel. The lowlands on each side subject to overflow are known as flood basins. They are connected with the river by old river channels, known as sloughs, through which the water enters the basins at ordinary and high stages. During flood stages the river overflows both banks, as the channel capacity in some places is only about one-third that of the flood plain of the river.

Butte basin lies on the east side of Sacramento River and northwest of the Sutter Buttes. At flood stages the water in this basin covers an area of from 30 to 150 square miles, and has a volume of from 115,000 to 460,000 acre-feet. It receives water from the river, from creeks, and during great floods from Feather River, and discharges into Sutter basin.

Sutter basin lies south of the Sutter Buttes, between Sacramento and Feather rivers. In time of flood the water surface has an area of 138 square miles, and the basin has a maximum capacity of 895,000 acre-feet. This basin discharges into Sacramento and Feather rivers near the mouth of the latter.

Colusa basin lies west of Sacramento River, and is bounded on the south by a ridge of débris brought down by Cache Creek. It is about 50 miles long and from 2 to 7 miles wide, and has a capacity at ordinary stages of 690,000 acre-feet. It drains into Sacramento River above Knights Landing.

American basin extends from American River to a point about 9 miles above the mouth of Feather River. It has an area of about 110 square miles, and contains at ordinary flood stages 345,000 acre-feet, its maximum capacity being approximately 575,000 acre-feet. It receives the water which escapes through breaks in the east banks of

Sacramento and Feather rivers, through the south-side levees of Bear River, and from the Sierra Nevada foothills between American and Bear rivers.

Sacramento basin is a long, narrow depression, east of Sacramento River and south of the city of Sacramento. It has been protected for a number of years from overflow by levees.

Yolo basin lies on the west side of Sacramento River below Knights Landing. It is the largest of the flood basins, and has a length of 40 miles and an average width of 7 miles. During floods it contains about 1,150,000 acre-feet of water. It is a by-pass for the excess flood water of the Sacramento. An outlet through Cache Slough, which enters the main river at the foot of Grand Island, discharges at times more than double as much as the main river. The effect of this body of water, which stands at the same elevation as the river, is to increase the high-water stage near the foot of Grand Island if the basin receives a large volume of water suddenly through a break in the west side of the levees. Much damage has been caused to the reclamation work on the delta island on this account.

The total approximate storage capacity of these basins, not including the Sacramento basin, is 3,800,000 acre-feet.

The Sacramento below Red Bluff flows in a channel that is in places raised above the surface of the country on either side. The banks are low and there are sloughs that lead the water into the overflow basins. The slope of the channel is small, so that the flow is sluggish. The channel cross section is much smaller than that of the flood flow, so that the river sometimes overflows its banks and floods the country for many miles on each side. The river was formerly navigable to Red Bluff, and there was a rise and fall of the tides at Sacramento of 2 feet in 1860. Now the tidal effect is not felt at Sacramento and the bed of the river there is higher than the surface of low water some years ago.

Feather River breaks through the foothills into Sacramento Valley at Oroville. Its mountain drainage is fan shaped and the water collected when rains are general sometimes causes tremendous freshets of short duration. The river has at such times overflowed its right bank and submerged the relatively high-plain lands northwest of the Sutter Buttes.

There has been a great change in the channel of this river in recent years. In 1849 it was a clear-water stream falling over bars of gravel and cobbles lying between well-defined banks to its junction with Yuba River. Tidal influence extended for some distance up the river. The bottom lands along Yuba and Feather rivers in their original condition were inundated only at times of extraordinary floods. Now Feather River below Yuba River has become the repository of so much mining débris that its channel has been nearly filled,

its bottom being nearly at the height of its former banks. The water plain at Marysville at low stage of Yuba and Feather rivers is now at least 15 feet higher than it was in 1849.

Feather and Yuba rivers were once navigable streams. Up to 1862 the Yuba was navigable all the year for ships and boats drawing from 9 to 10 feet of water, and during the entire season deep-water ships and steamers from around Cape Horn navigated to Marysville. At the present time the channel of Yuba River is entirely filled with mining débris and Feather River is practically unnavigable.

PRECIPITATION.

The monthly precipitation at 14 places in the Sacramento River drainage basin for the seasonal year 1903–4 is given in the table below, which shows clearly the excessive precipitation at all stations of high elevation in this watershed during February and March, 1904. The records for Red Bluff and Sacramento are taken as typical of the precipitation of the Sacramento Valley. Fifty per cent or more of the total yearly precipitation fell during these two months, the rainfall being from 100 to 250 per cent above the normal. The precipitation was 7.37 inches at Mount St. Helena on March 17 and 6.58 inches at Mount Shasta on March 15 and was 2 or more inches daily at several places. Some of this precipitation fell as snow and did not at once find its way into the streams as run-off; otherwise the resulting flood would have been much larger than it was.

Monthly precipitation at certain points in the watershed of Sacramento River, California, for the season 1903–4.

Basin and station.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
Upper Sacramento:													
Dunsmuir[a]	0.00	2.27	16.94	5.84	5.03	24.00	22.90	4.33	0.00	0.00	0.00	0.00	81.31
Shasta[a]	.17	2.05	19.67	4.78	2.79	24.86	16.37	7.84	.07	.00	.04	.00	78.64
Johns Camp[a]	.00	5.06	21.85	4.85	4.50	19.73	27.26	10.90	.00	.00	.00	.00	94.15
Feather:													
Quincy[a]	.35	1.53	14.08	3.72	2.46	22.10	10.83	1.97	.74	T.	.05	.12	57.95
Butte Valley[a]	.....	.....	15.90	5.50	4.20	22.90	22.10	6.65	.65	T.	.70	.90	[b]79.50
Yuba:													
Laporte[a]	.40	3.50	27.64	6.46	4.48	30.35	31.66	7.63	.98	.24	.10	.58	114.02
Bowman Dam[a]	.00	4.06	31.27	6.19	5.37	45.61	39.51	8.52	1.37	.15	.20	.11	142.33
American:													
Cisco[a]	.00	1.00	16.90	2.80	5.20	30.80	26.87	5.20	.80	T.	.00	.50	90.07
Georgetown[a]	T.	1.39	17.71	2.07	4.79	26.02	21.17	5.52	.81	.00	.00	.05	79.53
Cache Creek:													
Lakeport (near)[c]	.00	.36	5.29	3.18	1.40	8.78	7.74	2.17	.00	.....	.00	.00	28.92

[a] Authority of United States Weather Bureau.
[b] The period; year incomplete.
[c] Authority of United States Geological Survey.

Monthly precipitation at certain points in the watershed of Sacramento River, California, for the season 1903–4—Continued.

Basin and station.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
Putah Creek:													
Helen [a]	.00	2.75	27.62	5.63	4.52	34.22	31.48	8.12	.00	.20	.10	.00	114.64
Mount St. Helena [b]	.00	2.00	.....	6.75	3.37	28.34	26.14	5.19	.05	T.	.22	.00	72.06
Sacramento Valley:													
Red Bluff [a]	.00	.46	7.99	3.73	1.44	6.63	8.33	2.90	.04	T.	.11	00	31.63
Sacramento [a]	.00	.12	3.44	1.12	.45	5.26	5.43	1.02	.03	T.	T.	.07	16.94

[a] Authority of Andrew Rocca.
[b] Authority of the United States Weather Bureau.

GAGE HEIGHT AND DISCHARGE.

The United States Geological Survey had five gaging stations in this drainage basin during this flood—one on Sacramento River at Red Bluff, one on Feather River at Oroville, one on Yuba River at Smartsville, one on Stony Creek near Fruto, and one on Cache Creek near Yolo. The mean daily discharge during the fifty days of the flood (February 11 to March 31) is given in the table below. About 72 per cent of the total mountain and foothills drainage area of the basin is above these gaging stations. The daily discharge for the remaining 28 per cent has been estimated, and the total daily discharge for all the mountain and foothills area is given in the last column.

Daily mean gage height and discharge in Sacramento basin, February 11–March 31, 1904.

Date.	Sacramento River at Iron Canyon, near Red Bluff, Cal.		Stony Creek at Julians, Cal.		Cache Creek at Yolo, Cal.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Feet.*	*Sec. feet.*
February 11	3.30	11,040	4.20	210	2.50	270
February 12	3.30	11,040	9.00	5,270	5.95	1,998
February 13	6.30	22,360	6.25	1,630	9.25	4,400
February 14	6.30	22,360	5.45	942	5.50	1,705
February 15	17.35	84,790	8.25	4,055	5.25	1,555
February 16	[a] 28.00	184,600	12.25	15,450	16.75	11,250
February 17	15.20	69,560	8.25	4,055	8.75	4,012
February 18	11.20	45,280	7.20	2,660	7.00	2,700
February 19	9.55	36,940	6.65	2,035	5.80	1,900
February 20	9.90	38,620	5.85	1,265	5.10	1,465
February 21	12.50	52,600	7.85	3,480	4.90	1,350
February 22	20.30	108,480	11.75	13,200	11.00	5,900
February 23	16.60	79,320	8.85	5,015	14.75	9,275

[a] Gage height 9 a. m.; highest known gage height, 31.0, same night.

an gage height and discharge in Sacramento basin, February 11–March 31, 1904—Continued.

te.	Sacramento River at Iron Canyon, near Red Bluff, Cal.		Stony Creek at Julians, Cal.		Cache Creek at Yolo, Cal.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Feet.*	*Sec. feet.*
y 24	19.15	98,830	13.50	22,200	16.50	11,000
y 25	19.15	98,830	10.00	7,280	7.50	3,075
y 26	16.80	80,760	10.00	7,280	13.00	7,700
y 27	17.80	88,180	9.05	5,360	16.50	11,000
y 28	12.85	54,700	7.90	3,550	9.60	4,680
y 29	13.40	58,000	7.40	2,900	8.60	3,900
	13.10	56,200	7.20	2,660	7.85	3,338
	15.55	71,950	7.20	2,660	7.30	2,925
	14.40	64,260	7.10	2,540	7.05	2,738
	15.80	73,700	7.05	2,480	6.85	2,595
	14.70	66,220	6.75	2,145	6.65	2,455
	13.10	56,200	6.85	2,255	6.45	2,328
	16.30	77,200	7.55	3,085	6.35	2,262
	24.40	147,180	7.65	3,215	6.30	2,225
	18.95	97,200	7.25	2,720	6.20	2,160
0	17.90	88,940	13.25	20,700	14.75	9,275
1	15.80	73,700	9.25	5,720	20.75	15,250
2	14.70	66,220	7.85	3,480	12.00	6,800
3	13.30	57,400	7.35	2,840	10.75	5,675
4	15.80	73,700	8.65	4,680	10.60	5,540
5	17.25	84,050	8.00	3,690	10.50	5,450
6	18.30	92,040	7.60	3,150	10.40	5,360
7	(18.85)	96,400	10.50	8,560	11.65	6,485
8	19.40	100,880	9.75	6,700	16.50	11,000
9	18.30	92,040	8.85	5,015	11.75	6,575
0	19.40	100,880	8.90	5,100	10.55	5,495
1	16.20	76,500	8.00	3,690	10.25	5,225
2	13.50	58,600	7.45	2,960	10.10	5,090
3	12.40	52,020	7.20	2,660	11.00	5,900
4	11.50	46,900	6.95	2,365	9.80	4,840
5	10.40	41,100	6.80	2,200	9.80	4,840
6	8.80	33,380	6.65	2,035	9.65	4,720
7	11.50	46,900	8.35	4,205	9.50	4,600
8	14.70	66,220	10.50	8,560	16.75	11,250
9	18.20	91,260	9.35	5,905	14.50	9,050
0	14.80	66,880	8.55	4,520	11.70	6,530
1	13.00	55,600	7.30	2,780	10.40	5,360

***Daily mean gage height and discharge in Sacramento basin, February 11–March 31, 1904*—Continued.**

Date.	Feather River at Oroville, Cal.		Yuba River at Smartsville, Cal.		Mountain and foothill drainage area, 22,487 square miles.	
	Gage height.	Discharge.	Gage height.	Discharge.	Estimated discharge.	Run-off per square mile.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Sec. feet.*	*Sec. feet.*
February 11	3.25	3,150	5.70	1,880	22,408	1.01
February 12	9.00	12,900	10.50	12,340	95,554	4.29
February 13	7.15	8,550	8.50	6,740	68,231	3.06
February 14	5.95	6,680	7.50	4,550	51,587	2.32
February 15	11.65	23,250	9.50	9,350	180,369	8.09
February 16	20.35	94,000	20.00	58,000	570,014	25.58
February 17	16.75	59,975	(17.00)	41,000	298,266	13.38
February 18	11.85	24,250	(12.00)	17,880	147,436	6.61
February 19	10.45	17,900	(10.50)	12,340	110,214	4.94
February 20	9.55	14,575	(9.50)	9,350	94,682	4.25
February 21	9.65	14,925	(9.50)	9,350	118,077	5.30
February 22	17.80	69,300	20.30	59,800	442,141	19.84
February 23	16.40	57,000	14.30	27,660	279,554	12.54
February 24	21.50	105,500	20.30	59,800	542,216	24.33
February 25	18.70	77,750	13.50	24,080	328,167	14.72
February 26	17.15	63,450	12.40	19,480	277,421	12.45
February 27	16.05	54,025	11.20	14,800	251,436	11.28
February 28	13.90	37,400	10.60	12,680	169,296	7.60
February 29	12.55	28,400	10.30	11,700	152,750	6.85
March 1	11.65	23,250	10.00	10,780	138,296	6.20
March 2	11.95	24,800	9.60	9,630	152,558	6.84
March 3	12.15	26,000	10.00	10,780	149,724	6.72
March 4	13.05	31,450	10.90	13,720	174,889	7.85
March 5	12.55	28,400	10.90	13,720	162,746	7.30
March 6	12.00	25,100	10.20	11,380	139,488	6.26
March 7	12.05	25,400	10.60	12,680	168,548	7.56
March 8	15.35	48,400	12.50	19,880	295,970	13.28
March 9	14.70	43,350	11.10	14,440	217,998	9.78
March 10	15.65	50,800	13.10	22,380	345,474	15.50
March 11	14.30	40,350	11.10	14,440	218,318	9.80
March 12	12.35	27,200	10.50	12,340	165,973	7.45
March 13	11.95	24,800	9.80	10,200	143,209	6.42
March 14	11.85	24,250	10.70	13,020	174,824	7.84
March 15	12.20	26,300	10.60	12,680	182,462	8.19
March 16	11.75	23,750	10.50	12,340	183,153	8.22
March 17	15.80	52,000	14.80	30,040	308,023	13.82
March 18	20.45	95,000	15.50	33,500	380,434	17.07

NOTE.—Gage heights in parentheses are estimated.

Daily mean gage height and discharge in Sacramento basin, February 11–March 31, 1904—Continued.

Date.	Feather River at Oroville, Cal.		Yuba River at Smartsville, Cal.		Mountain and foothill drainage area, 22,487 square miles.	
	Gage height.	Discharge.	Gage height.	Discharge.	Estimated discharge.	Run-off per square mile.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Sec. feet.*	*Sec. feet.*
March 19	19.75	88,000	15.10	31,500	349,319	15.68
March 20	19.15	82,000	13.30	23,220	323,675	14.52
March 21	16.70	59,550	10.80	13,360	228,171	10.24
March 22	14.70	43,350	10.30	11,700	177,349	7.96
March 23	13.55	34,950	9.10	8,260	148,569	6.67
March 24	12.80	29,900	9.30	8,800	134,910	6.05
March 25	12.00	25,100	9.10	8,260	119,151	5.35
March 26	11.65	23,250	8.70	7,230	104,825	4.70
March 27	11.50	22,500	9.00	8,000	128,408	5.76
March 28	13.75	36,350	14.80	30,040	260,514	11.69
March 29	16.70	59,550	13.30	23,220	287,075	12.88
March 30	15.10	46,400	11.10	14,440	206,309	9.26
March 31	13.40	33,900	10.20	11,380	158,823	7.13

The total discharge from the mountain and foothill area was a maximum on February 16, the estimated mean daily rate of discharge being about 575,000 second-feet, or 25.58 second-feet per square mile. This flood rose very rapidly and also subsided rapidly. Four days after the maximum stage was reached the discharge was only 94,680 second-feet. The river at this time again rose very rapidly, and in two days a rate of 442,140 second-feet was attained. The greatest daily rate of discharge in March was on the 18th, when it was 380,436 second-feet.

By comparing the daily rate of discharge at the gaging stations it is seen that when the rate of flow from the whole mountain and foothill area is a maximum the rate at each of the stations is generally a maximum, but that occasionally the rate at one of the stations is a maximum while the rate from the total drainage basin is not a maximum. For example, the rate of discharge from the total mountain and foothill area was a maximum on March 10, but the rate at Red Bluff was a maximum on March 8.

Taking the rise that culminated on February 16 as a typical one, we may say that 2.8 per cent of the total run-off from the mountain and foothill area came from Stony Creek, 2 per cent from Cache Creek, 16.5 per cent from Feather River, 10.2 per cent from Yuba River, 32.2 per cent from Sacramento River above Red Bluff, and 36.3

per cent from the mountain and foothill area of the Sacramento basin not included in the areas gaged.

OBSTRUCTION OF CHANNEL.

The lower Sacramento has always been subject to overflow. The greatest recorded flood was in 1862. The precipitation at Sacramento for December, 1861, and January, 1862, during this flood, was 23.62 inches, while the precipitation for these months for 1903–4, as seen from the table, page 16, was only 1.57 inches. The maximum height attained was not as great as that of the 1904 flood, but the volume of water discharged was much greater. Some of the bottom land has been reclaimed by the construction of levees, so that the flood width of the river has been considerably reduced. The depths of the channels have been reduced also by the deposit of débris from hydraulic mining on the tributaries.

The reclamation of bottom lands along the river by the construction of levees was begun in 1852 * and has gone on steadily since that time. It is estimated that $20,000,000 has been spent by private parties, reclamation districts, the State of California, and the Federal Government in the reclamation of these lands and in correcting the channels of Sacramento and San Joaquin rivers. The levees in many districts have been repeatedly overtopped by floods. The problem of reclamation has been rendered more difficult on account of the fact that the beds of the streams in Sacramento Valley, particularly the Yuba, Bear, Feather, American, and the Sacramento below the mouth of the Feather, have been raised by the accumulation of débris brought down during floods. Some lands that were formerly exempt from overflow have been inundated recently by the accumulation of mining débris.

DAMAGE DONE BY FLOOD.

This flood swept away levees, fences, buildings, crops, and caused great damage to agricultural land. Approximately 800,000 acres of land were flooded. It is said that 50,000 acres of wheat were destroyed by breaks in the levees below Colusa. Orchards which had reached their most productive age were killed by the water standing upon them. The value of a portion of the submerged land was decreased by having from 2 to 4 feet of sand deposited upon it. On February 26 the levee on the left bank of Sacramento River broke at a point 2½ miles below the south line of the city of Sacramento. This was known as the Edwards break. The water escaping at this point backed up against the Y street levee of Sacramento and soon overtopped the cross levees to the south and reached Sacramento River

* Report of the commissioner of public works, 1895.

by way of Mokelumne River. About 10,000 acres of fertile and highly cultivated land in the Sacramento flood basin were inundated and remained so until the end of March. This area was planted to crops, orchards, gardens, alfalfa, etc.

The city of Sacramento was surrounded by water on three sides. On March 10 a severe windstorm from the southeast drove the waves against the Y street levee, and a threatened break was prevented only by continuous work.

The Edwards break is supposed to have been caused by the work of squirrels and gophers and the fact that the base of the levee is located upon a bed of quicksand. To this break may be traced the flooding of Staten, Tyler, and Bouldin islands on lower San Joaquin River. Before the repairs were completed the width of the gap in the levee was 1,400 feet and the total cost of closing it has amounted to $120,000.

It has been impossible to make a satisfactory estimate of the total damage caused by the flood of 1904. The most that can be said is that the loss amounted to several millions of dollars. Fortunately, there was no loss of life.

PREVENTION OF FUTURE DAMAGE.

After the flood of February and March, 1904, an engineering commission was appointed by the governor of California to report upon rectification of Sacramento and San Joaquin rivers and their principal tributaries and the reclamation of overflow lands adjacent thereto. This commission made its report to the commissioner of public works of California, December 13, 1904. It declares that—

> In Sacramento Valley and contiguous parts of San Joaquin Valley there are some 1,250 square miles of very fertile land that is subject to overflow from a very considerable flood in Sacramento River, and about 1,700 square miles from ordinary floods. The problem presented for solution is to devise means for preventing the inundation of these lands by having the flood water that must pass through this territory pass harmlessly into Suisun Bay, and to correct the existing faults of the river channel with a view to avoiding the floods and promoting the interests of navigation.

The plans recommended for the solution of the problem are—

> 1. To confine the flood waters to the channels of the various streams by means of levees, so as to prevent destructive inundation of the fertile lands.
>
> 2. To correct the alignment of the river by cut-offs where necessary, and to increase its channel capacity by mechanical means where current action fails to accomplish that purpose.
>
> 3. To collect the hill drainage, which now loses itself in the basins, in intercepting canals and carry it into the river at selected points.
>
> 4. To provide escape ways over levees for surplus flood waters during the period of channel development, and to provide for the disposal of this water in connection with the hill drainage.
>
> 5. To provide for the relief of the basins from accumulation of rain and seepage water by means of pumps wherever gravity drainage is not practicable.

It is proposed to construct lines of levees on both sides of Sacramento River, from Stony Creek on the west and Chico Creek on the east down to its mouth, including both sides of Old River and Steamboat Slough, except where existing levees are adopted into the system. The minimum distance between the levees is specified in each case, and wherever the distance between the present levees is less than this specified amount the width is to be increased, by the removal of the old levee on one or both sides of the river.

The estimated cost of carrying out the plan proposed is $23,776,000. The direct benefits to the entire valley to be realized as a result of this plan of improvement are the reclamation of a million acres of extremely fertile land and the placing of all in a position of assured safety from overflow, together with direct and indirect advantages to many associated interests, which, expressed in money valuation, reach at least $100,000,000 and assuredly justify the cost of the work.

SUSQUEHANNA RIVER FLOOD, PENNSYLVANIA.

By E. C. MURPHY.

From March 3 to 15, 1904, there was a very destructive flood on Susquehanna River, due to excessive precipitation, the rapid melting of ice and snow, and the formation of ice gorges along the river.

FORMER FLOODS.

Destructive floods are not infrequent on this stream, four notable ones having occurred in the past forty years. One of these occurred in March, 1865, and was due to excessive precipitation, accompanied by a rapid melting of ice and snow and the formation of ice gorges. Another occurred in June, 1889, and was due to an excessive and prolonged precipitation, which, in point of volume of water, was the greatest on record. A third occurred in May, 1894, was due to excessive precipitation, and reached a stage from 2 to 3 feet lower than the stage of the 1889 flood at McCalls Ferry. The primary cause of the fourth flood (March, 1904), to be described in this paper, was the breaking up of the ice at places along the stream in January, with the water at so low a stage that this ice instead of moving out of the river collected in places where islands and other obstructions had caused the formation of gorges. These gorges were solidified and increased in thickness by the low temperature of February, forming dams that backed the water, causing overflow of large areas. The warm rains of March 6 and 7 largely increased the volume of flow, causing these gorges to break and form other temporary gorges farther downstream. When these temporary gorges gave way great destruction was caused, bridges, buildings, and even islands being *completely* destroyed by the action of the ice and water.

FLOOD OF MARCH 8, 1904, ON SUSQUEHANNA RIVER AT YORKHAVEN, PA., AT ITS HEIGHT.

STREAMS AND DRAINAGE BASIN.

The Susquehanna drainage basin is one of the largest on the Atlantic slope and comprises an area of about 27,400 square miles, located mainly in eastern Pennsylvania. About 56 per cent of this basin is in the Allegheny Plateau, 31 per cent in the Allegheny Mountains, 6 per cent in the Allegheny Valley, and 7 per cent in the Piedmont Plateau. The Allegheny Plateau is characterized by high hills and deep valleys, the hills rising from about 500 to 800 feet above the valleys. The western part is more broken and has steeper slopes than the eastern part. The valleys contain much glacial drift and many of the hills are covered with timber. The mountain portion consists of a series of nearly parallel ranges, with steep slopes, through which the Susquehanna has cut its waterway, forming great water

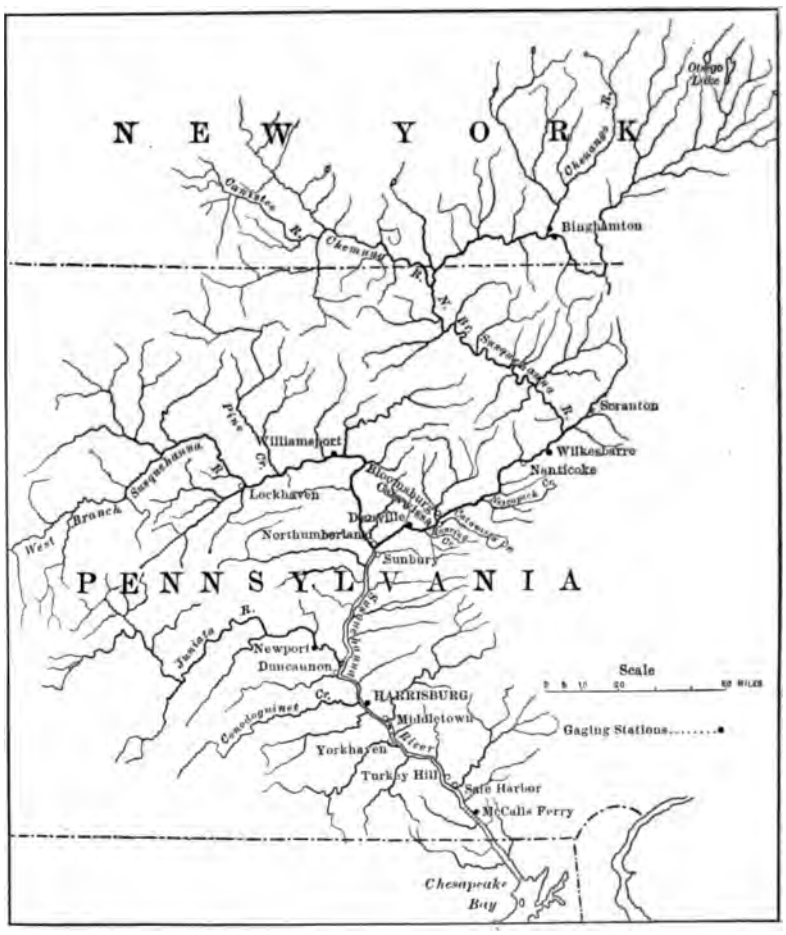


FIG. 1.—Drainage basin of Susquehanna River.

gaps. Below the mountain region the valleys are wider and the slopes less steep. The slope of the stream is comparatively small in this part of the drainage basin. The Piedmont Plateau region is composed mainly of farming land with low, well-rounded hills and very little forest area. The Susquehanna, like its tributaries in this part of the basin, has a very steep slope for its size, having a number of shoals with considerable fall.

The principal tributaries are Chenango River, which enters from the west at Binghamton, N. Y.; West Branch, entering Sunbury, Pa., and Juniata River, which enters from the west about 15 miles above Harrisburg. (See fig. 1.)

The slope of the river can be seen from the following table:

Profile of Susquehanna River.[a]

Locality.	Distance from mouth.	Height above sea.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Mouth	0	0	.....
State line	12	69	5.8
Mouth of Fishing Creek	20	100	3.9
Foot of Columbia dam	43	224	5.4
Foot of Conewago Falls	57	254	1.6
Above Conewago Falls	59	273	9.5
Harrisburg	69	298	2.5
Rockville	75	305	1.16
Clark Ferry dam, foot	84	336	3.4
Liverpool	99	378	2.3
Selinsgrove	116	421	2.5
Sunbury dam:			
Foot	122	422	.2
Crest	122	429	.....
Nanticoke dam:			
Foot	174	509	1.5
Crest	174	515	.....
Wilkesbarre	183	521	.66
Mouth of Lackawanna River	190	536	2.14
Mouth of Tunkhannock Creek	211	581	2.14
Mouth of Meehoopany Creek	223	604	1.9
Mouth of Wyalusing Creek	244	646	2.0
Mouth of Wysox Creek	258	687	2.9
Towanda	262	700	3.2
Athens	278	744	2.7
Otsego Lake	422	1,193	3.1

[a] *Gannett, Henry, Profiles of rivers: Water-Sup. and Irr. Paper No. 44, U. S. Geol. Survey, 1901, p. 17.*

ICE GORGE OF 1875 ON SUSQUEHANNA RIVER AT WILKESBARRE, PA.

PRECIPITATION.

The monthly precipitation and the variation from normal monthly precipitation from October, 1903, to March, 1904, at three places in this drainage basin are given below:

Monthly precipitation and monthly variation from normal in Susquehanna basin, 1903–4.

Place.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total.
Harrisburg, Pa.:	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Precipitation	2.62	0.88	1.92	3.11	1.54	2.72	12.79
Variation	− .4	−1.9	−1.1	− .5	−1.4	− .8	− 6.1
Scranton, Pa.:							
Precipitation	6.42	1.86	2.59	3.23	.92	2.10	17.12
Binghamton, N. Y.:							
Precipitation	5.74	2.26	2.12	2.11	1.16	2.11	15.5
Variation	+2.8	.1	− .7	− .8	−1.7	−1.0	− 1.5

From this table it may be seen that there was a deficiency of precipitation at these places of from 1½ to 6 inches preceding this flood. The deficiency at Binghamton would have been about 3 inches larger had it not been for the excessive precipitation at this place during the month of October.

While these data are not sufficient to enable us to state exactly the deficiency for the whole drainage basin, they are sufficient to indicate that the precipitation over the drainage basin for the six months prior to the flood was below the normal for such a period, and that the flood was not due to the large volume of water flowing, but to the ice gorges in the river.

ICE GORGES.

The following facts in regard to time of breaking up of ice gorges on this river are taken from the United States Weather Review.

The ice on Juniata River broke the latter part of February and formed a gorge at Duncannon. It broke on West Branch at Lockhaven at 2 p. m. March 3, moving out on a 12-foot stage. When the flood reached Duncannon, on March 4, it broke the gorge there and the ice in the river below, destroying Clarks Ferry bridge. The ice began to move at Fort Hunter, 7 miles above Harrisburg, at 10 a. m.

and at Harrisburg at 10.55 a. m. on March 4. The surface fluctuations of the river at Harrisburg on March 4 were as follows:

Gage height at Harrisburg, March 4, 1904.

	Height in feet.
8 a. m	13.5
12 m	16.0
1 p. m	20.0
3.15 p. m	23.3
11 p. m	21.3

A gorge formed near Middletown, 9 miles below Harrisburg, and another a short distance below Highspire, the water being 1.5 feet higher at the former place and 0.8 foot higher at the latter place than during the great flood of June 2, 1889. All the lowlands along this part of the river were flooded.

There was no material change in conditions on the main stream from March 4 to 8. The height of the water in the pools above the ice gorges fluctuated as the gorges opened and were closed again by floating ice.

Juniata, West Branch, and the headwaters of the main stream fell from March 4 until the morning of March 7, when mild weather and rain caused all the branches to rise rapidly. On the evening of March 7 the ice passed out of Roaring, Catawissa, and Nescopeck creeks. Early March 8 the ice began to move at Wilkesbarre, but in two hours formed a gorge and caused the stage to be 29 feet at noon. It broke at Pittston, above Wilkesbarre, about midnight of March 8, and, moving downstream, lodged on the gorge at Nanticoke, causing the water to reach 30.6 feet at Wilkesbarre, flooding more houses and causing several coal companies to suspend operations. The ice moved about 400 feet at Catawissa at 11.30 on March 9, carrying away two spans of the Catawissa bridge. Several movements of ice occurred in North Branch on March 9, indicating a general breaking up of the ice.

At Middletown at 10 a. m. on March 7 the stage of the river was 34.5 feet—that is, 5 feet higher than during the great flood of June 2, 1889. The gorge at Bainbridge, 14 miles below Harrisburg, moved on March 8, dislodging the gorge at Turkeyhill and forming a gorge below Safe Harbor, submerging the lower part of the town and destroying many houses and two bridges.

The ice started at Danville about 3.30 p. m. on March 9, carrying away the bridge at this place. About 5 p. m. it began to move at Wolverton, a few miles above Sunbury, and the portion of the great gorge between Sunbury and Boyds passed out, carrying away three

spans of the wooden highway bridge at Sunbury. A section of the gorge between Boyds and Rupert moved out at 2 p. m. on March 10, causing the river at Catawissa to fall 14 feet and improving the situation at Bloomsburg, where the water fell at the rate of 6 inches per hour during the afternoon. A section of the gorge at Rupert moved out about noon March 11 without destroying the Bloomsburg Bridge, as it settled back on its piers. The stage at Bloomsburg was 24 feet when the ice began to move, and fell to 12 feet shortly after the movement occurred. The ice was reported to be 6 feet in thickness when it broke up.

No further movement of ice was reported until March 21, when the gorge above Wilkesbarre began to disintegrate and pass downstream. A portion of the gorges in Susquehanna and Chenango Rivers near Binghamton moved out during the afternoon of March 24. The ice at Bloomsburg, which is near the center of the great gorge, began to move at 7 p. m. on March 24, and the gorge at Creasy broke at 3.30 p. m. on March 25 without doing much damage.

GAGE HEIGHT AND DISCHARGE.

The daily gage height and corresponding discharge at six of the gaging stations in this drainage basin during this flood are given below:

Daily gage height and discharge at gaging stations in Susquehanna drainage basin during flood of March, 1904.

Date.	Susquehanna River at McCalls Ferry, Pa.		Susquehanna River at Harrisburg, Pa.		Susquehanna River at Wilkesbarre, Pa.	
	Gage height.	Discharge.	Gage height	Discharge.	Gage height.	Discharge.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Feet.*	*Sec. feet.*
March 3	122.0	59,000	11.91	(a)	12.3	(a)
March 4	122.9	70,200	13.50	(a)	11.6	(a)
March 5	128.0	141,100	22.00	(a)	11.0	(a)
March 6	128.0	141,100	19.41	(a)	10.9	(a)
March 7	126.0	118,500	16.33	(a)	11.6	(a)
March 8	146.6	300,000	21.16	(a)	21.7	(a)
March 9	130.2	176,500	15.91	(a)	25.3	(a)
March 10	130.4	180,700	15.00	(a)	24.6	(a)
March 11	130.9	192,000	12.00	(a)	23.8	(a)
March 12	126.6	121,300	9.16	(a)	22.0	(a)

Daily gage height and discharge at gaging stations in Susquehanna drainage basin, etc.—Continued.

Date.	Susquehanna River at Binghamton, N. Y.		West Branch at Williamsport, Pa.		Juniata River at Newport, Pa.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec. feet.*	*Feet.*	*Sec. feet.*	*Feet.*	*Sec. feet.*
March 3	3.92	(a)	7.5	26,300	7.2	16,370
March 4	6.65	(a)	19.0	135,100	13.5	73,850
March 5	8.48	(a)	16.5	104,300	8.9	27,700
March 6	7.68	(a)	9.2	37,200	6.0	9,930
March 7	7.52	(a)	7.4	25,700	5.5	8,010
March 8	11.40	(a)	17.4	115,000	14.0	80,100
March 9	13.62	(a)	13.5	72,600	10.0	36,800
March 10	12.25	(a)	9.8	41,400	7.2	16,370
March 11	9.80	(a)	7.6	26,900	6.0	9,930
March 12	8.02	18,020	6.5	20,850	6.0	9,930

[a] Not computed on account of ice gorge.

The maximum daily gage height attained at the gaging station at Binghamton, N. Y., during this flood is seen from the table above to be 13.6 feet on March 9. This is 4 feet less than the recorded flood of this river at this place, so that the stage was only that of an ordinary flood at this place. Little damage was caused in this part of the drainage basin.

The maximum daily stage attained at the gaging station on the Juniata at Newport is seen from the table above to be 14 feet on March 8. This stream frequently attains a stage of 15 feet or more at this place during floods, so that this flood was of only ordinary magnitude at this place.

At the Williamsport gaging station on West Branch the maximum daily stage was 19 feet on March 4 and 17.4 on March 8. This station has been in operation only about three years, but during this period a maximum stage of 21 feet has been recorded.

The maximum daily stage reached during this flood at the gaging station at Wilkesbarre was 25.3 feet on March 9. This is 3.5 feet less than that attained by the great flood of 1869; the stage on March 9 during the ice gorge was 30.5 feet, however. It is seen from the table that the stage at this place was 23 feet or more for three consecutive days.

At Harrisburg a daily stage of 22 feet was reached on March 5 and 21.2 feet on March 8. Twice in the past thirteen years these stages have been exceeded. On March 29, 1895, it was 25.6 feet, and on March 2, 1902, it was 23.9 feet.

The maximum daily stage at the station at McCalls Ferry during this flood was 146.6 feet on March 8.

The following table gives the maximum height above low water of 1900 of the flood at five places along the river:

Flood height in 1904, in feet, above low water of September, 1900.[a]

Date.	Main river at McCalls Ferry (4 p. m.).	Main river at Harrisburg (7 a. m.).	North Branch at Wilkesbarre (8 a. m.).	West Branch at Williamsport (7.30 a. m.).	Juniata River at Newport (12 m.).
1904.					
March 3	9.0	11.9	9.0	7.4	4.4
March 4	9.9	13.5	11.2	18.9	10.7
March 5	15.0	22.0	16.0	16.4	6.1
March 6	15.0	19.4	14.9	9.1	3.2
March 7	13.4	16.3	15.4	7.3	2.7
March 8	33.6	21.2	26.3	17.6	11.2
March 9	17.2	15.9	28.5	13.4	7.2
March 10	17.4	15.0	24.0	9.7	4.4
March 11	17.9	12.0	21.9	7.5	3.2
March 12	13.6	9.2	19.9	6.4	3.2
Maximum height attained	[b] 33.6	[c] 23.3	[d] 28.5	[e] 18.9	.....

[a] Hoyt, J. C., and Anderson, R. H., Hydrography of Susquehanna River basin: Water-Sup. and Irr. Paper No. 109, U. S. Geol. Survey, 1905.
[b] March 8, 4 p. m.
[c] March 4, 3 p. m.
[d] March 9, 8 a. m.
[e] March 4, 7 a. m.

NOTE.—Maximum heights other than at McCalls Ferry were caused by backwater from gorges.

The following table gives the maximum, minimum, and mean discharge and corresponding gage height of Susquehanna River at Harrisburg, each year from 1891 to 1904:

Minimum, maximum, and mean discharge of Susquehanna River at Harrisburg, Pa., for 1891 to 1904, inclusive.[a]

Year.	Minimum.			Maximum.			Mean discharge.
	Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.	
		Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*	*Sec.-ft.*
1891	October 4 to 7, inclusive.	1.60	10,200	February 19	19.00	334,500	52,200
1892	October 31 to November 8, inclusive.	.50	4,070	April 6	14.65	224,200	37,250
1893	August 16 to 19, inclusive, and August 25.	.35	3,500	May 6	16.50	267,400	40,550

[a] Op. cit.

Minimum, maximum, and mean discharge of Susquehanna River, etc.—Cont

Year.	Minimum.			Maximum.			Mean dis-charge
	Date.	Gage height.	Dis-charge.	Date.	Gage height.	Discharge.	
		Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*	*Sec.-f*
1894	September 5 and 6	.25	3,160	May 22	25.60	543,500	39,9
1895	October 30 and 31	.05	2,570	April 11	13.65	205,400	29,3
1896	September 5 to 13	.25	3,160	April 1 and 2	14.60	223,200	34,6
1897	September 15 and October 21.	.50	4,070	March 26	11.50	165,300	32,3
1898	October 3 to 7	.65	4,740	March 24	15.65	245,900	40,4
1899	October 24 and 25	.15	2,850	March 7	13.00	193,000	31,0
1900	September 28 and 29.	−.04	2,360	March 2	13.10	194,900	29,9
1901	November 12	1.00	6,550	December 16	21.40	405,100	42,3
1902	September 23, 24, and 25.	.85	5,760	March 2	23.90	484,100	47,1
1903	October 7	1.40	8,850	March 2	16.85	276,500	54,5
1904	December 11	.84	5,708	May 22	-------	----------	32,3
	For the 14 years.	[a] −.04	[a] 2,360	----------	[b] 25.60	[b] 543,500	39,2

[a] September 28 and 29, 1900. [b] May 22, 1894.

The flood at McCalls Ferry reached a maximum at about 3.30 p. m on March 8, for a stage of 161.3 feet above sea level near the cable o the Lancaster side, and 159.8 feet on the York side. In about hal an hour the stage had fallen from 2 to 3 feet, and on the morning o March 9 it had fallen to 15 feet below maximum stage.

A discharge measurement was made at the cable during maximum stage by Mr. R. H. Anderson. The time of the passage of cakes o ice between two cables across the river 80 feet apart was observed a various places across the stream, and the surface velocity computed From the surface velocity and cross section the discharge was computed and found to be about 631,000 cubic feet per second.

There are several high-water marks of the flood of 1889 along the railway and canal near McCalls Ferry, made by eyewitnesses of that flood. These marks were connected by level, and the slope of the surface obtained. Ten sections were selected, and their area and wetted perimeter measured. From these data and a value of n the coefficient of roughness (0.05), the maximum discharge at these 10 stations was found by Kutter's formula to vary from 713,000 to 780,000 cubic feet per second, the mean of the 10 discharges being 730,000 cubic feet per second. The value of n, the coefficient o roughness, was computed from current-meter measurements of discharge at this place at a lower stage.

DAMAGE DONE BY FLOOD.

It is almost impossible to estimate the damage caused by this flood on Susquehanna River. The estimates made by the newspapers vary all the way from $2,000,000 to $8,000,000. The greatest loss probably occurred from Wilkesbarre to Sunbury, Pa. The big gorges at Keppsrun, Catawissa, and Nanticoke caused the submergence of large areas of lowland along the river. Kingston, Nanticoke, Dorranceton, Plymouth, Pittston, and other places along the river were partly under water. Many people were compelled to leave their homes, into which the water poured, filling cellars and in some cases the first story of the houses. Blocks of ice floated down, carrying away fences and porches and crashing into houses and causing much damage. The basements in many of the business houses were flooded, and goods damaged or destroyed. The railway tracks along the river were under water in many places, and the depots flooded. Great masses of ice, that required thousands of workmen to remove, were piled on the tracks. Several bridges across the river were destroyed or badly damaged. The Catawissa Bridge had three spans carried away. The Pennsylvania Railroad temporary bridge at Sunbury was destroyed. The Bandville highway bridge was destroyed, and the electric light and coke plant at that place was forced to suspend work. The highway bridge at Sunbury and that at Northumberland were partly destroyed. The highway bridge over Catawissa Creek and several other similar structures were destroyed or badly damaged.

The following is a rough estimate of the damage due to the flood as given in newspaper reports:

Damage from flood of 1904.

Pottstown to Sunbury [a]	$6,500,000
Dauphin County [b]	275,000
Lancaster County	275,000
York County [c]	200,000
Cumberland County	200,000
Perry County	200,000
Snyder County	125,000
Juniata County	100,000
Maryland County	100,000
Total	7,975,000

The loss and damage to State bridges was reported as $800,000.

[a] Of which $1,000,000 to $2,000,000 were in Wyoming Valley.
[b] Loss at Middletown about $100,000.
[c] Most of the damage occurred at Yorkhaven and vicinity.

PREVENTION OF FUTURE DAMAGE.

This flood was not due to the large volume of water flowing in the river, but to ice gorges in it. The precipitation for the six months prior to the flood was below the normal, and the melting of snow was not excessively rapid. The ice in the river broke up in January at a low-river stage, and before the river had time to clear itself the temperature fell and the ice collected, forming gorges at narrow places in the stream, river bends, and islands. Snow, water, and continued low temperature added to the thickness of these ice gorges. When the warm rain of early March melted the snow and increased the volume of flow of the river, these gorges held the water back somewhat like a dam and caused the overflow of lowlands. When the gorges finally gave way they swept away everything in their path—fences, trees, buildings, and even small islands.

There does not appear to be any practicable remedy for floods due to ice gorges on streams. It is almost impossible to keep an open channel during the winter. Explosives have been used to break up an ice gorge, but the stream is frequently blocked for many miles, and if the gorge is broken at one place the ice soon forms at another gorge farther down the stream, especially if the temperature is below freezing. The only remedy is to remove, as far as possible, the causes that stop the movement of the ice.

MOHAWK RIVER FLOOD, NEW YORK.[a]

From March 25 to 31, 1904, there occurred a flood on Mohawk River, in New York State, which, while not the largest and most destructive in the recorded history of this stream, was yet sufficiently so to call for the following brief description.

STREAMS AND DRAINAGE BASIN.

Mohawk River is the chief tributary of Hudson River and drains an area of 3,490 square miles. It rises about 40 miles from the east end of Lake Ontario, in New York State, flows in a general southerly direction a distance of about 140 miles, and empties into the Hudson at Waterford.

Its principal tributaries are East and West Canadian creeks, which enter from the north, and Oriskany and Schoharie creeks, which enter from the south. Reels Creek is a small stream that enters the Mohawk from the north near Utica. Starch Factory Creek is a comparatively small stream that enters from the south near Utica. Sauquoit Creek is a tributary of Starch Factory Creek.

The river valley has generally a width of from 1 to 2 miles, made

[a] Prepared mainly from data furnished by Robert E. Horton, district hydrographer.

up of rich alluvial meadow land. At Little Falls it cuts through a gorge whose walls are from 500 to 600 feet high. The country gradually rises from the river valley to the hills, attaining an elevation of several hundred feet above the river. On the north the hills are succeeded by an elevated plateau, having mountain peaks of from 2,500 to 3,000 feet in elevation above sea level. About 20 per cent of the drainage area has an elevation from 100 to 500 feet, 37 per cent from 500 to 1,000 feet, 27 per cent from 1,500 to 2,000 feet, 13 per cent from 2,000 to 2,500 feet, and about 3 per cent above 2,500 feet. The part of the drainage basin north of Mohawk River is thickly forested; that on the south is mainly deforested. The tributaries are all quick filling, having a comparatively steep slope and rapid velocity, with little storage, but enter the main river at points a considerable distance apart. The Erie Canal parallels the river from the mouth to a few miles above Rome, and is supplied from the river and some of its tributaries.

The following table[a] shows the slope of the river from the mouth to Rome:

Slope of Mohawk River, New York.

Locality.	Distance from mouth.	Height above sea.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Mouth	0	12	.....
Lower aqueduct (fall nearly all at Cohoes)	4	162	37.5
Schenectady	19	214	3.5
Mouth of Schoharie Creek	42	270	2.4
Three miles east of Utica	95	393	2.3
Four miles east of Rome	112	418	1.5
Rome, above feeder dam	115	431	4.3

Fig. 2 shows the principal streams of this drainage basin; also the precipitation lines and gaging stations.

PRECIPITATION AND TEMPERATURE.

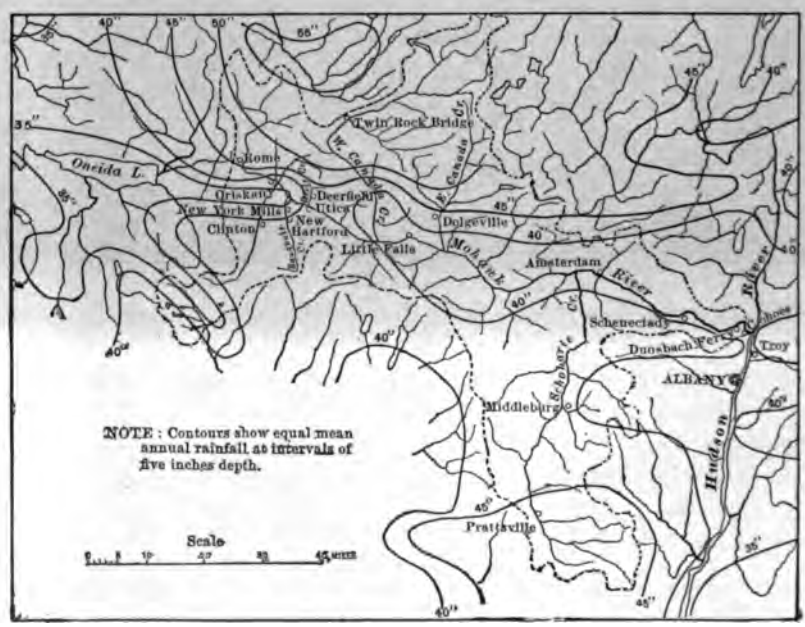
From the precipitation lines on fig. 2 it is seen that the mean annual precipitation in this basin varies from about 40 to 55 inches. The precipitation for the six months preceding this flood at four places in the drainage basin is given in the following table, which

[a] Water-Sup. and Irr. Paper No. 44, U. S. Geol. Survey, 1901, p. 15.

also gives the monthly excess or deficiency at Albany and the accumulated deficiency there for the period in question:

Precipitation in Mohawk River watershed, Oct., 1903, to Mar., 1904.

Place.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total.
Albany:	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Variation from normal	+2.50	+1.30	+1.10	−0.04	−1.6	−0.70	− 2.6
Precipitation	6.09	1.65	1.59	2.51	1.17	1.94	14.95
Amsterdam	6.89	1.85	2.10	3.74	1.91	2.82	19.31
Little Falls	7.58	2.10	2.23	2.33	2.28	3.17	19.69
Rome	7.95	3.11	2.98	5.27	2.55	3.68	25.54



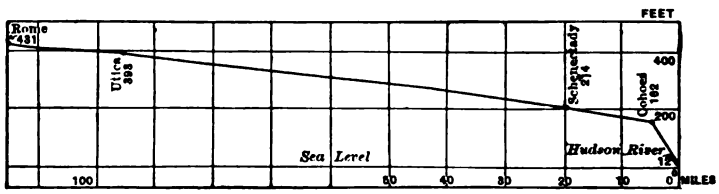


FIG. 2.—Drainage basin and profile of Mohawk River.

It is seen from the table that there is an accumulated deficiency at Albany for the six months of 2.6 inches. The snow accumulation of the winter attained a maximum measured-water equivalent of

7.42 inches at Utica on March 7. This gradually decreased to 5.92 inches of water in the form of snow on March 21.

The temperature and precipitation immediately preceding the flood are shown in the following table:

Precipitation and temperature on Mohawk River watershed, March 22 to 27, 1904.

Date.	Little Falls.		Rome.	
	Rainfall.	Mean temperature.	Rainfall.	Mean temperature.
	Inches.	°*F.*	*Inches.*	°*F.*
March 22	0.00	34	0.30	37
March 23	.71	38	.00	38
March 24	.00	34	.00	34
March 25	.35	43	.20	46
March 26	.18	42	.33	4[illegible]
March 27	.00	26	.00	32
Total	1.24		.83	

DISCHARGE.

The rise in temperature on March 25 and 26, as noted above, caused a flood of considerable magnitude owing to the rapid melting of snow, although but little rain fell.

The total discharge and the discharge per square mile of Mohawk River at Little Falls during floods of 1901, 1902, and 1904 are given in the following table:

Flood discharge of Mohawk River at Little Falls, N. Y.

[Drainage area, 1,306 square miles.]

Date.	7 a. m.		5 p. m.	
	Second-feet.	Second-feet per square mile.	Second-feet.	Second-feet per square mile.
1901.				
December 13	4,818	3.69	4,818	3.69
December 14	6,643	5.09	18,284	14.01
December 15	21,628	16.57	21,628	16.57
December 16	28,500	21.83	21,420	16.41
December 17	11,108	8.51	9,015	6.91
December 18	6,294	4.82	5,269	4.04
December 19	4,349	3.33	3,912	3.00
December 20	2,365	1.81	1,930	1.48

Flood discharge of Mohawk River at Little Falls, N. Y.—Continued.

Date.	7 a. m.		5 p. m.	
	Second-feet.	Second-feet per square mile.	Second-feet.	Second-feet per square mile.
1902.				
February 27	1,451	1.11	1,732	1.33
February 28	2,383	1.83	4,473	3.43
March 1	11,256	8.62	15,356	11.76
March 2	28,505	21.83	28,505	21.83
March 3	25,093	19.22	21,693	16.62
March 4	19,993	15.32	12,993	9.95
March 5	11,229	8.60	9,156	7.01
March 6	7,848	6.01	7,470	5.72
March 7	6,403	4.90	5,378	4.12
March 8	4,889	3.74	4,889	3.74
1904.				
March 19	2,029	1.55	2,038	1.56
March 20	2,071	1.58	2,359	1.81
March 21	2,359	1.81	2,583	1.98
March 22	2,827	2.17	2,827	2.17
March 23	4,149	3.18	5,721	4.38
March 24	6,672	5.11	7,579	5.80
March 25	9,321	7.14	12,497	9.57
March 26	20,220	15.48	----------	----------
	[a] 22,920	[a] 17.55	[b] 24,720	[b] 18.96
	----------	----------	26,620	20.38
	----------	----------	[c] 27,220	[c] 20.84
March 27	22,120	16.94	22,120	16.94
March 28	16,590	12.70	16,090	12.32
March 29	11,197	8.58	10,767	8.27
March 30	9,286	7.12	8,685	6.65
March 31	8,658	6.63	8,083	6.19

[a] 10 a. m. [b] 2 p. m. [c] 7 p. m.

The latest flood lasted from March 25 to 31, attaining a maximum on March 26 of 20.84 cubic feet per second per square mile.

The discharge of three small streams near Utica during this flood are given in the following table:

Record of flood discharge, 1904.

SYLVAN GLEN CREEK NEAR NEW HARTFORD, N. Y.

[Drainage area, 1.18 square miles.]

Date.	Time.	Second-feet.	Second-feet per square mile.
March 22	8 a. m	0.357	0.302
	5 p. m	2.07	1.75
March 23	8 a. m	15.24	12.87
	5 p. m	14.90	12.62
March 24	8 a. m	5.10	4.32
	5 p. m	13.27	11.26
March 25	7.30 a. m	12.33	10.42
	5 p. m	66.80	56.58
March 26	8 a. m	43.06	36.51
	5.30 p. m	12.01	10.16
March 27	8 a. m	2.67	2.26
	5 p. m	1.05	.889
March 28	8 a. m	1.05	.889

STARCH FACTORY CREEK NEAR NEW HARTFORD, N. Y.[a]

[Drainage area, 3.4 square miles.]

March 21		2.88	0.847
March 22	8 a. m	3.38	0.994
	5 p. m	10.35	3.043
March 23	8 a. m	61	17.934
	6 p. m	63	18.522
March 24	7 a. m	65	19.11
	6 p. m	128	37.63
March 25	7.30 a. m	128	37.63
	6 p. m	372	109.368
March 26	7.30 a. m	315	92.61
	6 p. m	128	37.632
March 27	8 a. m	48	14.112
	6 p. m	32	9.408
March 28	8 a. m	19.5	5.733
	6 p. m	19.5	5.733
March 29	8 a. m	14.5	4.263
	6 p. m	21	6.17
March 30	8 a. m	14.5	4.26
	6 p. m	29.5	8.67
March 31	8 a. m	19.5	5.73
	6 p. m	32.3	9.50

[a] Not including Graefenberg diversion, which is estimated at 0.25 second-foot per square mile.

Record of flood discharge, 1904—Continued.

STARCH FACTORY CREEK NEAR NEW HARTFORD, N. Y.—Continued.

Date.	Time.	Second-feet.	Se pe
April 1	8 a. m.	19.5	
	6 p. m.	337	
April 2	7 a. m.	40	
	6 p. m.	48	
REELS CREEK AT DEERFIELD, N. Y. [Drainage area, 4.4 square miles.]			
March 22		8.72	
March 23		24.31	
March 24		19.43	
March 25	7 a. m.	49.8	
	5 p. m.	135.9	
March 26	7 a. m.	179.7	
	5 p. m.	214.3	
March 27	7 a. m.	175.5	
	5 p. m.	188.5	
March 28	7 a. m.	49.9	
March 29		33.6	
March 30		30.5	

The very large discharge of 109.62 second-feet per square m
Starch Factory Creek at 6 p. m. on March 25 is worthy of sp
note.

The following table gives the discharge at maximum stage o
Mohawk and its small tributaries during this flood:

Discharge of Mohawk River and tributaries March 25 and 26, 1904.

Stream.	Time of maximum.	Drainage area in square miles.	Maximum discharge in second-feet.	Se fe se
Mohawk River at Rome [a]	March 26, p. m.	158	4,320	
Oriskany Creek at Oriskany	March 25, 5 p. m.	144	4,170	
Sauquoit Creek at New York Mills	March 26, 11 a. m.	52	1,150	
Starch Factory Creek near Utica	March 25, 6 p. m.	3.4	372	1
Reels Creek at Deerfield	March 26, 5 p. m.	4.42	214.3	
Sylvan Glen Creek near Utica	March 25, 5 p. m.	1.18	66.8	
Budlong Creek near Utica	March 25, p. m.	1.13	136.4	1
Mohawk River at Little Falls	March 26, p. m.	1,306	27,200	

[a] At State dam.

It is seen that the maximum discharge of the small streams occurred March 25, and the maximum discharge of the main stream did not occur until the evening of the 26th.

The following table gives the discharge of the Mohawk at Little Falls during the floods of February, 1891, December, 1901, March, 1902, and March, 1904:

Flood discharge of Mohawk River in 1891, 1901, 1902, and 1904.

Date.	Second-feet.	Second-feet per square mile.
February, 1891	26,260	20.7
December 16, 1901	26,280	20.7
March 2, 1902	[a] 28,500	20.7
March 26, 1904	27,200	20.8

[a] Revised computation.

The principal results of the 1901, 1902, and 1904 floods of Mohawk River are summarized in the following table:

Summary of Mohawk River floods of 1901, 1902, and 1904.

Year.	Period.	Duration in hours.	Mean second-feet per square mile.	Mean depth run-off in inches.	Total discharge during flood, in cubic feet.
1901	December 13 to 20	179	8.70	2.39	7,237,454,976
1902	February 27 to March 8	224	9.18	3.19	9,591,264,000
1904	March 19 to 31	336	7.92	4.12	10,183,289,472

The results obtained on the small streams near Utica during this flood are summarized in the following table:

Summary of small-streams discharge during flood of 1904.

Stream.	Drainage area in square miles.	Duration of freshet.			Average discharge in second-feet per square mile.	Total yield during freshet.	
		From—	To—	Days.		Inches run-off.	Gallons.
Starch Factory Creek[a]	3.40	March 22	March 29	7	33.33	8.67	512,278,000
Reels Creek	4.42	March 24, noon.	March 29, noon.	5	29.92	5.56	407,230,000
Sylvan Glen Creek	1.18	March 22, noon.	March 27, noon.	5	19.06	3.55	72,570,000

[a] Including Graefenberg diversion.

The maximum discharge of West Canada Creek during this flood occurred on the afternoon of March 27, and was 7,068 cubic feet per

second, or 21 cubic-feet per second per square mile, at the gaging station at Twin Rocks Bridge, this being far below the recorded flood maximum of this stream. The cause of this flood of March 26 on the upper Mohawk was apparently the rapid melting of snow on the watershed from Rome to Little Falls, together with ice blockades in the river. A drop in temperature on the 27th checked the rapid melting of snow, and the flood rapidly subsided.

DAMAGE DONE BY FLOOD.

The damage done consisted mainly in the flooding of all lowlands along the river, of cellars, houses, and in some cases the basements of business places; and in the delay or stoppage for a short time of railway traffic on the New York Central Railroad and street railroads of some of the cities along the river. In some places along the river ice gorges formed and flooded large areas. One of these was at Akin. Almost the whole of the village of Fort Hunter was flooded by this ice gorge.

GRAND RIVER FLOOD, MICHIGAN.[a]

From March 20 to April 8 occurred the largest and most destructive flood in the recorded history of this stream, and in all probability the largest in this drainage basin for a century.

STREAMS AND DRAINAGE BASIN.

This is the largest river drainage basin in Michigan, comprising an area of 5,570 square miles, draining into Lake Michigan. It is nearly oval in shape, has a length of 135 miles, and a maximum width of 70 miles. It slopes rapidly for about half its length from an elevation along its eastern rim of about 400 feet above Lake Michigan toward the west and toward the river. Its lower half has a very slight slope and contains some flat, highly permeable land with lakes and ponds having no outlets. Fig. 3 shows the stream and its tributaries, the gaging and precipitation stations, and a profile of the river from the mouth to Jackson, a distance of about 210 miles. From the mouth to Ionia, a distance of 81 miles, the average slope is only 0.6 foot per mile. From Ionia to Jackson, 130 miles, the slope is 2.36 feet per mile.

The three principal tributaries above Ionia are Red Cedar, Looking Glass, and Maple rivers, all entering from the east a considerable distance apart. The three principal tributaries that enter below Ionia are the Thornapple from the south and the Flat and Rouge from the north. These three enter within a distance of less than 18 miles, in

[a] Prepared mainly from data furnished by Robert E. Horton, district hydrographer.

which the slope is only 0.6 foot per mile; they have a marked effect upon the flood conditions.

PRECIPITATION AND TEMPERATURE.

The monthly precipitation at five places in this drainage basin for the six months prior to this flood is shown in the following table,

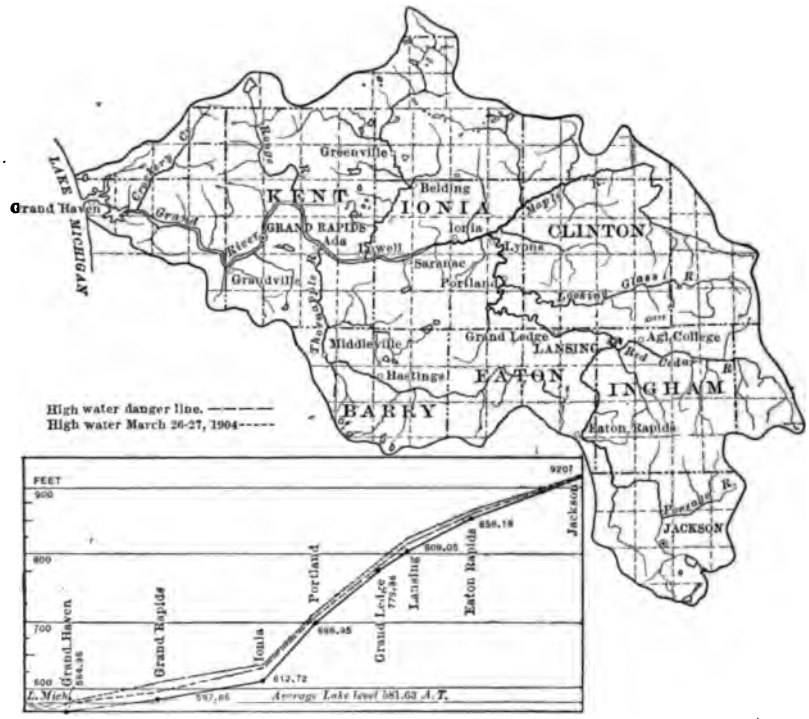


FIG. 3.—Drainage basin and profile of Grand River, Michigan.

as are also the monthly excess or deficiency and the accumulated deficiency at Grand Rapids for the six months:

Precipitation in Grand River basin, October, 1903, to March, 1904.

Place.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Grand Haven	1.04	1.24	1.31	0.78	0.80	2.16	7.33
Grand Rapids	− .4	−2.6	− .6	−1.5	− .8	+2.00	−3.9
	2.31	.85	2.29	1.47	1.78	[a] 4.39	13.09
Hastings	1.55	1.57	1.98	2.23	1.70	5.05	14.08
Lansing	1.99	1.45	2.06	2.82	1.53	([b])	.....
Jackson	1.43	1.43	2.07	2.80	2.60	3.72	14.05

[a] The depth of snow at Grand Rapids March 20 was 1 inch.
[b] The depth of snow at Lansing March 6 was 20 inches.

It is seen that there was an excess of 2 inches in March, but a deficiency of 3.9 inches for the six months October to March. The daily temperature and precipitation during the flood are given in the following table:

Daily precipitation and temperature at Grand Rapids and Lansing, Mich., March 22 to 28, 1904.

Date.	Grand Rapids.		Lansing.	
	Precipitation.	Temperature.	Precipitation.	Temperature.
	Inch.	*°F.*	*Inch.*	*°F.*
March 22	0.43	42	0.00	40
March 23	.00	40	.00	38
March 24	.00	48	.84	46
March 25	.66	45	.32	38
March 26	T.	26	.04	21
March 27	.07	20	T.	20
March 28	T.	28	.00	28

It is seen that this flood was caused by a moderate rainfall in conjunction with melting snow, due to high temperature.

GAGE HEIGHT AND DISCHARGE.

The gage height and corresponding discharge at the gaging stations at Grand Rapids and Lansing during this flood are given in the following table:

Mean daily gage height and discharge of Grand River, Michigan, March 20 to April 9, 1904.

Date.	Grand Rapids.[a]		Lansing.	
	Gage.	Discharge.	Gage.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
March 20	9.20	16,700	----------	----------
March 21	9.30	17,000	6.60	2,840
March 22	10.65	19,500	7.80	3,930
March 23	11.45	21,400	11.39	9,780
March 24	15.60	30,300	13.78	14,560
March 25	18.01 (18.09)	35,800	16.65	20,300

[a] From Lyman E. Cooley, C. E.

Mean daily gage height and discharge of Grand River, Michigan, March 20 to April 9, 1904—Continued.

Date.	Grand Rapids.		Lansing.	
	Gage.	Discharge.	Gage.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
March 26	(19.05)	37,800	18.02	23,040
March 27	19.50 (19.75)	39,400	16.05	19,100
March 28	19.20 (19.36)	38,500	14.05	15,100
March 29	18.13 (18.22)	36,000	12.80	12,600
March 30	16.75 (16.77)	32,900	10.86	8,720
March 31	15.40	29,900	11.07	9,140
April 1	14.45	27,800	11.75	10,500
April 2	13.80	26,800	11.40	9,800
April 3	13.80	26,600	11.10	9,200
April 4	13.80	26,600	10.55	8,100
April 5	12.80	24,500	8.95	6,920
April 6	11.20	20,700	8.22	4,880
April 7	10.50	18,800	7.70	3,880
April 8	9.55	17,400	7.38	3,520
April 9	9.40	17,200	7.55	3,680

Figures in parentheses are elevations corrected for the flow which passed across the west side and entered the river about 1.4 miles below Fulton street; they are used in the volume equivalent.

The flood at Grand Rapids lasted from March 21 to April 8, reaching a maximum on March 27, with a gage height of 19.75 feet and a discharge of 39,400 cubic feet per second, or 8.04 cubic feet per second per square mile. For five days the gage reading was 18 feet or more.

The flood at Lansing reached a maximum on March 26, one day earlier than at Grand Rapids. The maximum daily flow at Lansing was 18.7 second-feet per square mile, which is about 2.36 times greater per square mile than that at Grand Rapids, and yet the area overflowed and the damage done by the flood at Grand Rapids was much greater than at Lansing, due to the difference in rapidity of flow.

The flood profile of this river is shown in fig. 3, and the height of the flood above danger line, as shown by gages along the river, is given in the table following.

Flood profile of Grand River, Michigan, 1904.

Place.	Gage height.	Height above danger line.
	Feet.	*Feet.*
Grand Rapids	20.45	9.7
Ionia	27.55	3
Portland	14.44	2.9
Grandledge	14.10	7.9
Lansing	19.45	8.6
Eaton Rapids	9.20	2.7

It is seen that the stage was from 7.9 to 9.7 feet above the danger line at Lansing, Grandledge, and Grand Rapids.

DAMAGE DONE BY FLOOD.

At Grand Rapids the river began to overflow its banks on the evening of March 24, and the water did not return within the banks of the river until March 31. More than 1,500 houses were flooded, the west part of the city for a width of several blocks being overflowed to a depth in places of 5 feet. The city gas-light plant was cut off by the water and the city was without light for several nights. Ten thousand employees of the various industries along the river were thrown out of work.

The following extract from one of the Bay City, Mich., newspapers describes the flood conditions in Michigan on March 31:

> The floods in Michigan are the worst since 1887. Lowlands are everywhere completely under water and roads are in most cases flowing streams.
>
> Numerous dams have been washed out or so badly undermined as to be practically ruined. Bridges, both railroad and highway, are in the same condition. Railroad traffic has been stopped entirely on account of washouts of bridges or sections of track. Factories have been put out of business by water rising in their basements sufficiently to put out their fires, and several cities are in darkness because of a similar condition of affairs in their lighting-plant power houses.
>
> Stores in the business portion of cities are basement full, and in many cases the water is flowing through them on the ground floors. Many families have been forced to leave their homes.
>
> The damage will be something enormous, both in the actual destruction of property and in the stoppage of business. No figures can be given, but it is conservatively estimated that the loss will run into the millions.

PREVENTION OF FUTURE DAMAGE.

Destructive floods may occur on this river from the rapid melting of a comparatively small amount of snow, accompanied with a not excessive rainfall, the small slope of bed of the stream from Grand

Rapids to Lake Michigan (about 0.6 foot per mile) being insufficient to carry off the water as rapidly as it comes down from the upper watershed. The remedy for the consequent overflow consists in giving the stream an abundant unobstructed waterway and using levees where the benefits derived from them will justify the cost of their construction.

WABASH RIVER FLOOD, INDIANA.

By F. W. HANNA.

STREAMS AND DRAINAGE BASIN.

The drainage area of Wabash River covers the major portion of the State of Indiana and a considerable territory in eastern Illinois.

FIG. 4.—Drainage basin of Wabash River.

In shape it resembles a huge fan, the axis of which lies along a straight line connecting its mouth with the town of Wabash, Ind., near its source. In the upper course of the river the right-hand and

sive. The zero of this gage is very close to low-water mark for the river at this place.

Maximum yearly gage height on Wabash River at Mount Carmel, Ill., 1885–1904.

Date.	Gage height.	Date.	Gage height.
	Feet.		*Feet.*
January 8, 1885	24.7	January 25, 1895	7.5
May 22, 1886	19.8	July 29, 1896	14.9
March 14, 1887	22.0	March 13, 1897	26.4
April 5, 1888	20.6	March 30, 1898	27.0
June 19, 1889	20.8	January 23, 1899	19.5
January 14, 1890	24.1	March 14, 1900	19.0
March 2, 1891	22.0	March 19, 1901	17.5
April 13, 1892	21.5	December 25, 1902	17.0
May 8, 1893	24.5	March 12, 1903	22.3
February 16, 1894	13.6	April 2, 1904	27.1

The movement of the waters of these successive storms down Wabash and White rivers toward the Ohio can readily be followed, in a general way, by a study of the gage heights of the United States Geological Survey records at Logansport, Ind., on the Wabash, and at Shoals, Ind., on the east branch of White River, in connection with those of the United States Weather Bureau at Mount Carmel, Ill., on the Wabash, below the White. The zero of the Geological Survey gage at Logansport is about 1 foot below low-water mark, while the zero of the gage at Shoals on White River is about 63 feet below low water. A partial list of the gage heights from March 1 to April 25 is appended below:

Gage height and discharge showing progress of flood at Logansport, Shoals, and Mount Carmel, March and April, 1904.

Date.	Logansport.		Shoals.		Mount Carmel.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.
1904.	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*
March 1	9.90	31,710	67.60	8,610	10.50
March 21	6.20	14,880	67.70	8,860	15.50
March 22	8.30	24,140	68.00	9,610	15.70
March 23	8.10	23,220	74.40	25,870	16.00
March 24	6.68	16,940	75.20	27,950	16.70
March 25	6.85	17,670	78.40	36,270	17.70
March 26	13.45	51,980	87.10	58,880	20.70

ght and discharge showing progress of flood at Logansport, Shoals, and Mount Carmel, March and April, 1904—Continued.

Date.	Logansport.		Shoals.		Mount Carmel.
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.
1904.	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*
.....	14.84	56,880	87.70	60,450	21.90
.....	13.05	49,380	92.80	73,710	23.10
.....	10.32	33,840	95.20	79,950	24.10
.....	7.50	20,520	94.90	79,170	25.50
.....	9.10	27,880	93.40	75,270	26.50
.....	12.22	43,380	91.00	69,030	27.00
.....	13.00	47,130	88.80	63,310	27.10
.....	13.10	47,630	87.20	59,150	26.60
.....	11.06	37,430	85.60	54,990	26.10
.....	7.65	21,220	84.40	51,870	25.60
.....	5.73	12,940	83.40	49,270	25.30
.....	4.88	9,530	80.20	40,950	25.20
.....	4.45	8,220	73.20	22,750	25.10
.....	4.70	9,080	68.40	10,610	24.60
.....	3.90	6,400	66.80	6,610	20.00
.....	2.60	2,770	65.20	2,820	6.70

DAMAGE DONE BY FLOOD.

always very difficult, if not entirely impossible, to determine nage done by a flood. Inconvenience, suffering, and loss of may result from floods, and these are not reducible to mathe- statement. Even the property losses are difficult to estimate, ons not entirely ruined are so damaged, defaced, or spoiled by oaking as to take away the joy of their use, if not their prac- ility. Various attempts have been made to ascertain the of damage wrought by the Wabash flood of 1904, through the es of county commissioners, city councils, and railroad officials. ning up this matter the Indianapolis News of March 29 says:

stimated the damage in this county will reach $2,225,000 and north of ty an additional $1,000,000. Eleven lives have been lost in the Indi- l so far, and the total property loss in the State has been estimated $8,000,000 to $10,000,000. At Madison the county commissioners esti- e loss to bridges at $40,000. In Wabash County the loss is $50,000, hich is in the city. At Peru the loss is $100,000. Reports from Mey- that the loss in that vicinity will be $25,000. Reports from Bloming- hat the loss in that county will be $70,000.

This estimate was made before the great flood in the lower Wabash region was creating its greatest havoc with all kinds of property. Railroads, municipalities, highways, farms, in fact every kind of property in reach of the waters—and their reach was high and wide—suffered untold damage.

The damage to the railroads throughout the entire State of Indiana, and especially in the southern portion, was very great. Many of the roads on portions of their lines were unable to run trains for nearly a week, some of the small towns not being able either to receive or transmit mail for several days. Trains were detoured by all sorts of means to reach their final destinations, running without any hope of time schedule. Culverts and bridges, not only of railroads, but of highways as well, were swept out by the rush of waters through waterways insufficient at best and made more so by tremendous collections of drift.

The Indianapolis News for March 30 prints the following estimate of damages in Indianapolis to engineering works, principally bridges, prepared by Mr. Juep, city engineer:

Damages to engineering works at Indianapolis, Ind., March, 1904.

Bridges, etc.:	
East Tenth Street Bridge	$8,000
Highland Avenue Bridge	7,000
Dorman Street Bridge	7,000
East Ohio Street Bridge	8,000
Capitol Avenue Bridge and repairs	15,000
East Michigan street repairs	1,500
Washington Street Bridge, Irvington	2,500
Indiana Avenue Bridge abutments	7,000
Meridian street retaining walls, repairs to Barth Avenue Bridge, Indiana avenue and Cottage avenue retaining walls	5,000
Grand avenue culvert	75
Repairs to Liberty Street Bridge	50
Henry Street Bridge	8
Merrill street retaining walls for sewers	25
Merrill street and Senate avenue bridges	200
McCarthy Street Bridge	400
Delaware Street Bridge (new), over Pogues Run	10,000
Ray Street Bridge	300
Additional flood walls for protection of bridges	4,000
Levees and miscellaneous:	
Raymond street	350
Fall Creek, in five different places	3,500
Other important improvements and repairs of levees along White River	4,000
Cleaning, scraping and regraveling streets and alleys	30,000
Culverts washed out	3,000
Repairs to block pavement	10,000
Cleaning out Pogues Run and State ditch	15,000
Repairs to sidewalks	5,000

vees and miscellaneous—Continued.

Providing floodgates for sewers	$3,000
Repairs to temporary bridges over White River	6,000
Northwestern avenue temporary bridge	2,500
West Tenth Street Bridge	3,000
Sewer work and repairs and catch basins	5,000
For drainage of flooded districts, cutting levees, and rebuilding	1,500
Refilling washouts in streets	1,000
Total	168,908

Reports from other parts of the Wabash territory showed that the ımage was as great as in the vicinity of Indianapolis. The county mmissioners of Daviess County reported 50 bridges damaged and 18 tirely washed away in that county alone. The big steel bridge over hite River at Bloomfield was taken out, and large structures at ırious other places were swept away, crippling wagon, electric, and eam roads relentlessly.

All of the large railroad embankments in the bottom lands of hite and Wabash rivers were especial points of attack by the waters. wing to their obstructing nature, a head of several feet caused such eavy pressure as to start percolation and ultimate disintegration. t Hazleton, on the Evanston and Terre Haute Railroad, in the wer White River region, the situation was serious. The following ctract from the Evansville Courier of April 1 is not only illustrative this point, but of many others throughout the flooded districts:

Hazleton, Ind., March 31.—Three hundred workmen and four dirt trains are rking night and day to save the big fill north of Hazleton. The heavy rain dnesday night and the continued backing of flood water on the upper side the embankment forced a stream of water through the fill early Thursday rning. Thirty thousand sand bags had been piled along the track for a mile anticipation of a break, and the workmen at once began piling them into crevasse. They were unable to make headway against the wash, and by t night a dozen streams were trickling through the embankment and slowly shing it away.

At a late hour last night the break was reported to be in worse condition an in the morning in spite of all that had been done. The water stands 6 et higher on the upper side of the embankment than on the lower.

It is probable that more damage was done to the farms and farmıg interests than to any other class of business or property. Many arms were washed full of ditches; others were covered with several ches or feet of sand, and thousands of acres were flooded. The reaking of many levees throughout the valleys greatly increased e destruction. The following newspaper dispatches give someing of an idea of the damage done by this cause:

Vincennes, Ind., March 28.—The Wabash River levee, 10 miles north of here, oke in two places last night, flooding more than 15,000 acres of the finest nd in Knox County. The water rushed through fields, sweeping everything

before it. The farmers were warned in the afternoon that the levee was and it is believed that no lives were lost. Reports say that houses were off their foundations and the loss will amount to thousands. One breal about 75 feet wide; the other was 300 feet wide. Groundhogs or b beings are supposed to have caused the breaks. Other places in the leve weak, and big damages may come at any time. Farmers say that all the covered by water is killed.—*Indianapolis News.*

Sullivan, Ind., March 29.—The break in the township levee is now 13 wide. Three hundred feet of the Illinois Central tracks to the west o Riverton Bridge form a dam over which the water is flowing into the bo at a rapid rate. Much live stock has been killed.—*Evansville Courier.*

Clay City, Ind., March 30.—Eel River has been sweeping through its in this county, doing much damage to farms and railroads. The 7-foot constructed by the Lewis Township Improvement Company last year at of many thousand dollars to protect farm lands on the west side of "th Bend" is said to be ruined, without having afforded any returns for the and labor it represented. It was proposed to build a similar levee on the site side of the stream, but the project has been abandoned.—*Indiana News.*

The breaking of these levees, added to the water already flowin on unprotected tracts of land, produced extremely disastrous res Thousands of acres of growing wheat were either partly or to destroyed. Large amounts of grain and hay in store were ei destroyed or carried away. A loss of 20,000 bushels of corn in township alone was reported. Houses, barns, sheds, farm im ments, and live stock were swept away. Fifty head of dead c were seen floating in the drift near Mount Carmel.

In addition to the great damages already discussed, every t within the reach of the flood suffered heavy loss. Some of the s towns were entirely drowned out; others were isolated and ran s of provisions; all were partly submerged, cellars were filled water, merchandise ruined, furniture spoiled, water supplies shut light plants closed down, and business completely paralyzed. In midst of all this many people suffering from disease died from e sure; some were drowned in attempting to escape from the fl others lost their lives in trying to save property either of their or their neighbors; and still others were drowned in heroic attempting to save lives.

PREVENTION OF FUTURE DAMAGE.

The proper construction of levees is always a matter of vital im tance, inasmuch as they invite people to inhabit districts not ot wise tenable and encourage their spending considerable sums money through the confidence imposed in their protection. I usually found upon inspection of levees that have failed that a additional inches in height, a few additional feet in width, a l extra precaution in their protection and care would have enal

them to meet the flood crisis efficiently. The recent experience with the levees in Wabash Valley should lead to the rectifying of any such errors as these in that vicinity. Careful inspection should be made for the purpose of locating any and all defects of the above nature and immediate steps taken to repair them. Where there is a State engineer such matters should be under his charge, and recommendations should be made by him. In the cases where burrowing animals are especially bad, or where from any cause percolation is extremely likely to occur, and where the value of the property protected will permit, narrow concrete walls may be used to prevent the digging of holes through the embankment. This method is necessarily very expensive, but there are exceptional cases where the value of the protected property will warrant its use.

The straightening, widening, and deepening of river channels may be made a means of flood prevention. This must be done, however, in such a way as not to harm one portion of the valley by benefiting another. For instance, if all the headwater streams of the river are so improved as to bring the upper flood waters hurriedly down into the lower valley, where neither natural nor artificial means abundantly exist for their disposal, their field of destruction is merely transferred and their power for evil intensified. On the other hand, if a stream is improved in its lower valley or in any portion of its valley where ample drainage is furnished below the improved portion, great benefit must result.

In the case of the recent Wabash flood the greater part of the destruction took place in the lower valley in and about the junction of White and Wabash rivers. With the exception of a few isolated cases, the water channels in this region were less able to dispose of the waters delivered to them than those in any other portion of the drainage area. Evidently any improvement of the nature under discussion in the upper valleys without a corresponding increase of the carrying capacity of the lower-valley channel would be unwise. If the lower Wabash channel was improved so as to meet the additional demand on it, then the straightening, deepening, widening, and diking of some of the tributaries of this stream would be very beneficial. This is especially true of both branches of White River, which is extremely low banked and winding.

Often serious local flood damage is caused by the narrowing of the river channels by bridge piers, railroad embankments, highway grades, and other obstructions. The natural waterway is reduced for a given stage of water to a half, and often much less, of the original and natural one. The consequence is that the water is backed up several feet and property is seriously inundated that should have been free from the flood. As an instance of this, the situation in the flood

under discussion on White River at Shoals, Ind., may be cited. The town of Shoals consists of two parts, designated East Shoals and West Shoals. West Shoals is situated on ground on the right side of White River, lying mainly above high-water limit; East Shoals occupies chiefly a high rocky knoll immediately adjacent to the left bank of the stream. This eminence is exceptionally high at its central part next to the river, but slopes off toward low ground in all three of the remaining directions. The ordinary river channel runs adjacent to this bluff and carries stages of 15 to 20 feet of water. When the water gets higher it naturally spreads out over a flat several hundred feet wide on the right side. Still greater elevations of water surface originally caused the water to flow around to the left of the above-mentioned knoll. During the 1904 flood a maximum stage of about 35 feet above low water was reached. Had the river-channel waterway been what nature had prepared for it, it would have been four or five times as wide and several times as large as it was, and the water would not have risen to any such stage as it did. A highway grade and a railroad embankment made the surplus waterway on the right of the main channel useless, and a railroad embankment also prevented the water from passing around the knoll to the left as it naturally would. The result was that these obstructions served as a dam that raised the water several feet higher than it would naturally have risen. Much property on the lower margins of the knoll was flooded that should have been high and dry. The highway bridge has a length of only 445 feet between abutments, and the railroad bridge, a short distance below, is about the same length, and the maximum discharge of 80,000 second-feet was forced to pass through this space. The capacity of this waterway was also reduced by end contraction on the right bank. It is a notable fact that a high, solid embankment bridge approach on a low flat covered with several feet of water causes an action at the bridge similar to end contraction in a weir.

By obtaining slope, wetted perimeter, coefficient of roughness, and area of waterway the necessary increase in the length of the bridges to enable the channel to carry the flood at this point without causing undue rise might be computed. The computation is not made, as the situation is not critical enough to cause action on the computed results. This special case is cited at length as being one that came under the writer's observation and as being typical of many others throughout the flooded territory. Many instances from various places are reported where the unnatural rise caused by such obstructions as these has been 6 or 7 feet. Very often this rise has resulted in serious damage. Such cases demand the services of an engineer who is capable of determining what may be done to prevent future similar occurrences.

BELLE FOURCHE RIVER FLOOD, SOUTH DAKOTA.[a]

During the early part of June, 1904, the northern part of the Black Hills, South Dakota, was visited with excessive rainfall, which caused the Belle Fourche and other streams in that region to reach the highest known stage since 1883 and to do much damage to property along their banks.

STREAMS AND DRAINAGE BASIN.

Belle Fourche River, sometimes called North Fork of Cheyenne

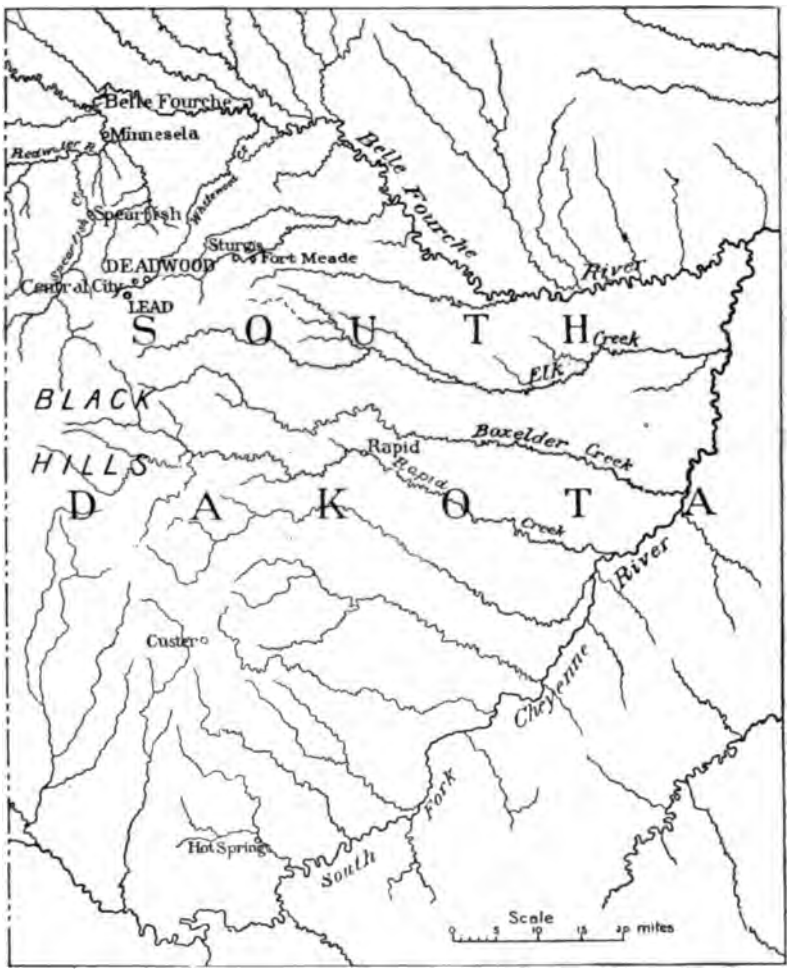


FIG. 5.—Part of Black Hills drainage.

River, rises in the northeastern part of Wyoming and flows in a gen-

[a] Prepared mainly from data furnished by R. F. Walter, engineer.

Flood data of the Belle Fourche and tributaries, June, 1904.

Stream and place.	Drainage area.	Maximum discharge.		Total discharge.
		Total.	Per square mile.	
	Sq. miles.	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*
Belle Fourche River at Belle Fourche, S. Dak	3,250	6,270	1.81	45,000
Redwater River at Belle Fourche, S. Dak	1,015	8,110	8.00	34,000
Rapid Creek at Rapid	410	1,170	2.85	7,400
Belle Fourche River below mouth of Whitewood Creek		20,000		

At no time was there a violent downpour, but all water c and dry runs gradually became torrents, carrying before them logs, trees, and débris, damming the channels. In many of the bowlders weighing a ton or more were rolled along by the water

DAMAGE DONE BY FLOOD.

The rainfall over the "hills" was much heavier than on the p and as the waterways in the former were much smaller than i latter the upper parts of the streams became raging torrents. B the main channels the smaller creeks and dry runs became to and discharged large volumes of water. Four lives were lost. greatest damage was done along Spearfish and Whitewood c where the channels were contracted in many places by railroa other improvements, and parts of the towns of Deadwood, Ce City, and Spearfish were under water.

At Deadwood the water of Whitewood Creek reached a heig 8 feet above normal and 2 feet above danger line, flooding the l part of the town, undermining many buildings, washing out of the railroad track of the Chicago and Northwestern and Bur ton and Missouri River railroads, completely destroying the bridges in Deadwood, and doing other damage all along its cours

Along Whitewood Creek the list of damages is given as follo

Damages from Belle Fourche flood.

City of Deadwood, bulkheads and bridges washed out and damage to streets	$2
Lawrence County	6
Chicago and Northwestern Railroad	3
Burlington and Missouri River Railroad	6
Private damage	2
Total	20

Along Spearfish Creek the Burlington and Missouri River Railroad in the canyon was almost completely washed out and the Government fish hatchery demolished; also considerable damage to streets and bridges in the town of Spearfish, as well as many private residences and orchards. All mill dams and canal heads were more or less damaged. The damage in Spearfish, outside of the railroad damage, will reach $20,000.

All the smelters along Whitewood Creek were forced to close down for some time, and the Homestake mine was shut down for the first time in twenty years on account of inability to secure fuel and the excess of water in the mine. Pl. IV, *B*, illustrates the damage to Chicago and Northwestern Railway along this stream.

Along Belle Fourche River, which receives all the water from the northern hills, no damage was done.

Redwater River, the main branch of the Belle Fourche, was from one-fourth to one-half mile wide and considerable damage was done to meadows along its course.

KANSAS FLOODS.

By E. C. Murphy.

The floods on Neosho, Verdigris, and Osage rivers in eastern Kansas in July, 1904, were larger and more destructive than any other recorded floods on these streams. The flood on Arkansas River in southern Kansas only lacked 0.8 foot of being as high as during the great flood of 1877. The flood on Kansas River, while of a stage several feet less than that of the May flood of 1903, was, nevertheless, greater than any recorded prior to that one.

PRECIPITATION.

The rainfall in eastern Kansas prior to this flood is thus described by Mr. P. Connor in the Monthly Weather Review for July, 1904:

The spring and early summer months, like those of 1903, in Kansas and western Missouri were abnormally wet. At Kansas City there was an excess of nearly 17 inches of precipitation from March 1 to July 8, the date of the highest water. Fortunately for this community and interests below Kansas City, the most violent storm occurred outside the Kansas—commonly known as the Kaw—watershed. The rainfall in Kaw Valley, while far too heavy and frequent for good farm work, was so distributed that the streams could carry it off without overflowing their banks until July 6, although twice in June rather heavy rains on consecutive days caused a good many of them to become almost bank full in some places. On the morning of July 4 rather heavy rains were reported in Kaw Valley and northwestern Missouri, with the larger streams of Kaw Valley at ordinary stages. On the morning of July 5 only ordinary rains were reported over the same territory. There was, as yet, no cause for serious

apprehension, but on the afternoon and the night of July 5 uniformly rains fell over the greater portion of Kaw Valley and northwestern Mi At Kansas City the fall was 2.31 inches in eighteen hours, and it was heavy along Kaw River to Topeka and along the Missouri to some d below St. Joseph. The great quantity of rain that fell in the basin at th tion of Missouri and Kaw rivers had immediate effect in raising the ri Kansas City, and, in consequence, the Missouri had risen 2.7 feet by the m of July 6, placing it 1.1 feet above the danger line. Kaw River rose 4 to

The monthly precipitation at several places in southeastern K and adjacent States is given in the following table:

Monthly precipitation and variation from normal in southeastern Kans adjacent States, January to July, 1904.

Place.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.
North Platte, Nebr	Variation	−0.2	−0.4	−0.2	−0.6	+0.9	+1.10	+2.2
	Precipitation	.32	.06	.52	1.52	3.63	4.43	4.90
Kansas City, Kans	Variation	− .4	−1.2	+3.3	+3.8	+6.1	− .4	+2.0
	Precipitation	.77	.69	5.51	6.69	10.70	4.56	6.25
Topeka, Kans	Variation	− .1	−1.6	+ .5	+2.0	+2.0	− .9	+1.4
	Precipitation	.92	.16	2.62	4.70	6.96	3.88	6.37
Dodge City, Kans	Variation	− .4	− .6	− .9	.0	+1.2	−1.3	−1.4
	Precipitation	.03	.02	.04	1.54	4.42	2.02	1.71
Wichita, Kans	Variation	− .8	−1.2	+2.4	− .3	+1.5	+ .7	+4.2
	Precipitation	.12	.04	4.23	2.65	5.74	5.69	7.46
St. Louis, Mo	Variation	+1.0	−2.0	+4.4	−0.5	−1.7	− .4	− .7
	Precipitation	3.15	.84	7.87	3.25	2.88	4.64	3.09
Oklahoma, Okla	Variation	+ .8	− .9	−1.8	−1.2	−1.2	+9.6	−2.6
	Precipitation	2.18	.04	.26	1.51	4.31	12.33	1.07
Fort Smith, Ark	Variation	+1.1	−2.9	− .5	−2.7	− .4	−1.8	−1.4
	Precipitation	3.48	.85	3.75	2.39	4.38	6.12	3.09
Emporia, Kans	Precipitation	.42	.09	4.01	3.15	8.32	9.51	8.90
Fort Scott, Kans	do	1.58	.57	1.69	10.34	6.23	12.88	8.12
Independence, Kans	do	1.44	.16	1.58	3.44	4.26	11.78	9.12
Winfield, Kans	do	1.13	T.	1.48	2.01	6.47	13.22	8.96
Hartshorn, Ind. T	do	2.35	.48	4.37	3.68	4.83	15.00	.....
Okmulgee, Ind. T	do	3.37	.08	1.94	1.27	10.66	13.94	.....
Bonham, Tex	do	2.26	1.72	.22	3.78	5.93	11.49	2.11

The monthly and the accumulated excess or deficiency for seven months January to July are also given for several of t places. These figures verify Mr. Connor's statement in regard t precipitation in eastern Kansas, and in a measure define the e and magnitude of the precipitation prior to this flood.

This excessive precipitation caused floods on Osage, Neosho, Verdigris rivers larger than ever known before. Compared wit storm that preceded the great flood on Kansas River in 1903, it be said that that of 1904 did not cover as large an area, was n intense, occurred about one month later in the season, and was tral over an area from 200 to 300 miles farther south.

A. MISSOURI PACIFIC AND UNION PACIFIC RAILWAY BRIDGES OVER KANSAS RIVER AT KANSAS CITY DURING FLOOD OF 1904

B. DAMAGE TO CHICAGO AND NORTHWESTERN RAILWAY ALONG WHITEWOOD CREEK, SOUTH DAKOTA.

KANSAS RIVER FLOOD.

GENERAL STATEMENT.

The greatest flood of Kansas River on record or in the memory of the oldest inhabitants living along the stream occurred May 23 to June 13, 1903.[a]

The flood of July, 1904, although it did not reach to within about 8½ feet of the height attained by that of 1903 at the United States gaging station at Lecompton, was, however, second to it in recorded height. Its estimated discharge was about 60 per cent of that of the flood of 1903 and about double that of the flood of April 26, 1897, which was the greatest in twenty-one years prior to 1903. The area flooded in 1904, while much less than that flooded in 1903, was nevertheless large, and, as the flood occurred about a month later than in 1903, it prevented the maturing of ordinary crops on the flooded area.

The effect of the 1903 flood on Kansas River was to deepen and widen the channel and in some places, notably near Manhattan and St. Marys, to straighten it by cutting off bends in the stream. A short distance south of the latter place a new channel about 4 miles long was formed and a few miles farther downstream another, one-half mile long, was cut across an oxbow bend. At many places along the concave bank washing took place, and where the banks were not protected erosion occurred, resulting in some places in the destruction of several acres of land. This erosion of bed and banks supplied a vast amount of material that was deposited on the flooded area. In places this deposit consists of from 2 to 6 inches of silt that enriches the land and in other places of from 2 to 6 feet of sand that completely ruins it. It is estimated that 10,000 acres of fine farming land along the river, valued at $200 per acre, were thus practically destroyed.

FLOOD NEAR KANSAS CITY.

The flood of 1903 destroyed 16 bridges in the vicinity of Kansas City, only one of which had been removed from the stream bed prior to the flood of 1904. Several temporary pile bridges had been constructed across the river between the dates of the two floods. These and other obstructions collected drift, retarded the flow, and increased the area of overflow. One of these pile bridges, the Rock Island Railway bridge, was destroyed by this flood, and other bridges were damaged to some extent.

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[a] For a description of the Kansas River basin and of the flood of 1903 and the destruction wrought by it, see Destructive floods in the United States in 1903: Water-Sup. and Irr. Paper No. 96, U. S. Geol. Survey, 1904.

Gage height and discharge.—The following table[a] gives the flu tuations of Missouri River at the Hannibal Bridge at Kansas Cit and of Kansas River at the Stock Yards Bridge (about 3 miles fro the Hannibal Bridge), at Topeka, and at Manhattan during the flood

Fluctuations of Kansas and Missouri rivers, July 1 to 13, 1904.

Date.	Missouri River.	Kansas River.			
		Topeka.	Manhattan.	Stock-yards gage, Kansas City.	Slope per mile.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
July 1	.....	11.10	11.70	16.30	.....
July 2	20.20	9.90	9.30	17.00	0.93
July 4	.....	7.50	9.00	15.50	.....
July 5	19.40	8.60	10.50	15.25	.53
July 6:					
8 a. m.	22.10	14.00	16.40	19.90	1.30
12 m	.....	16.10	17.00	21.65	.....
July 7:					
8 a. m.	23.20	20.50	16.50	24.10	2.23
12 m	.....	21.00	16.00	24.95	.....
1 p. m.	.....	20.90	16.20	25.25	.....
2 p. m.	.....	20.80	16.10	25.50	.....
3 p. m.	.....	20.50	16.00	25.80	.....
5 p. m.	.....	20.10	16.00	26.30	.....
6 p. m.	.....	19.80	16.00	26.45	.....
7 p. m.	.....	19.60	16.20	26.60	.....
8 p. m.	.....	19.50	16.40	26.75	.....
July 8:					
8 a. m.	25.20	18.90	16.00	27.50	2.73
9 a. m.	.....	18.80	15.90	27.50	.....
11 a. m.	.....	18.70	15.80	27.60	.....
12 m	.....	17.60	15.50	27.70	.....
1 p. m.	.....	17.50	15.50	27.80	.....
3 p. m.	.....	17.30	15.50	27.60	.....
5 p. m.	.....	17.10	15.50	27.40	.....
July 9:					
7 a. m.	24.80	15.50	15.60	26.00	2.33
8 a. m.	.....	15.30	15.60	25.90	.....
9 a. m.	.....	15.10	15.50	25.80	.....
10 a. m.	.....	15.00	15.40	25.70	.....
11 a. m.	.....	14.90	15.40	25.60	.....
12 m	.....	15.00	15.30	25.55	.....

[a] Data furnished by Mr. H. A. Wise, engineer Kansas City Stock Yards Company.

Fluctuations of Kansas and Missouri rivers, July 1 to 13, 1904—Continued.

Date.	Missouri River.	Kansas River.			
		Topeka.	Manhattan.	Stock-yards gage, Kansas City.	Slope per mile.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
July 9:					
2 p. m.	.....	14.90	15.20	25.40	.....
4 p. m.	.....	14.80	15.00	25.00	.....
July 10:					
7 a. m.	.....	14.00	14.00	22.85	.....
12 m.	.....	13.40	13.90	22.25	.....
July 11, 8 a. m.	21.90	12.70	13.70	20.00	1.300
July 12, 8 a. m.	20.30	12.00	13.30	17.80	1.100
July 13, 8 a. m.	19.10	11.80	13.60	16.20	.967

The gage on the Hannibal Bridge is the property of the United States Weather Bureau, and the readings of it were furnished by Mr. P. Connor. The datum of this gage is 5.8 feet lower than that of the stock-yards gage. It is seen that this flood reached its maximum height at 1 p. m. on July 8 at a gage reading of 27.8 feet, or a height of 28 feet above low water. The maximum height was reached at Topeka at noon July 7 and at Manhattan at noon July 6. The crest of the 1903 flood reached an elevation at the Hannibal Bridge about 10 feet greater than that of 1904. The difference in elevation of the crest of these floods at the stock yards must have been several feet greater than this on account of the much greater choking effect due to the collection of drift at the Union Pacific Railway bridge.

Column 6 gives the slope of the surface in feet per mile from the Stock Yards Bridge to the Hannibal Bridge during this flood. The slope is not constant, but varies directly with the stage. The greatest slope was about 2.73 feet per mile. During the 1903 flood the slope of the surface from the Union Pacific bridge to the mouth of the Kansas was about 4.34 feet per mile. For a distance of about 7,000 feet upstream from the Union Pacific bridge the slope was about 1.26 feet per mile. Farther up the river the slope was about 1½ feet per mile. The slope of Kansas River for some miles from its mouth is affected by the stage of the Missouri. It was a very fortunate occurrence that during the floods of both 1903 and 1904 Missouri River was not at its highest stage. If the great floods in this river had been coincident, the damage due to overflow in Kansas City would have been even greater than it was.

A flood-discharge measurement of Missouri River was made at

Hannibal Bridge May 12, 1904, for a mean gage reading of 2((about 5½ feet below the crest of the flood of 1904), and gave a of 28,036 square feet, with a discharge of 152,300 cubic feet per A flood-discharge measurement of Kansas River was made o 12, 1904, from the elevated-railroad bridge in Kansas City, for height (Hannibal Bridge gage) of about 20 feet, or a surfac tion (stock-yards datum) of 15.8 feet. The width between abu at this bridge is about 595 feet; the maximum depth, 25.9 feet 10,125 square feet; discharge, 58,900 cubic feet per second; t waterway under the bridge is 21,320 square feet. Both bank river at this point are several feet lower than the surface bridge, as the new bridge is about 6 feet higher than the which was destroyed in 1903.

Necessary waterway.—With the aid of Kutter's mean- formula we may compute the necessary width of a trapezoida way, with side slopes 1 to 1, to carry the flood of 1903 with mum depth of 30 feet. The estimated maximum discharg United States gaging station at Lecompton was 233,000 cu per second. Adding 8 per cent of this volume for the vol ceived between Lecompton and Kansas City we have 251,7 feet, or in round numbers 252,000 cubic feet per second as charge of Kansas River at Kansas City. The slope from t above is about 2.75 feet per mile. The coefficient of roughn about 0.030. From these data we find that the mean velocity about 10 feet per second, and that the bottom width of the tra area necessary would be 710 feet, and the top width 770 fee waterway would have permitted the flood of 1903 to pass City with a surface height not greater than that during the 1904—that is, a surface elevation at the elevated-railroad b 20 feet (stock-yards datum). Some of the bottom lands wo been flooded under those conditions unless low levees had b structed on each side of the river. If the channel width is r to 580 feet with vertical sides, surface slope of 2.75 feet p then the depth must be about 39 feet. In these computat allowance is made for reduction of waterway due to colle drift in front of piers or to the piers themselves.

Pl. IV, A, shows the Missouri Pacific and Union Pacific bridges across Kansas River in Kansas City when the flood 7, 1904, had begun to recede. The Missouri Pacific bridg was the only one across the Kansas River at Kansas City that destruction in 1903. The new Union Pacific bridge is at the s vation above low water as the old one, and the channel unde not been widened; in fact, the only effort made in Kansas City vent loss due to floods between the dates of these floods was struction of a few of the new bridges at a few feet greater e

than the old ones which were destroyed. The channel has not been widened, although at one place it is less than 450 feet in width. The spans of the bridges have not been lengthened, the channel has not been cleared of wreckage nor deepened, nor have levees been constructed to prevent overflow. The 1904 flood, although it did not reach within several feet of the height of the 1903 flood, nevertheless overflowed many acres of bottom land, drove a large number of people from their homes, and destroyed many thousand dollars' worth of property. Pl. V shows the areas submerged during the flood of 1903 and during that of 1904.

Recommendations of army engineers.—A board of army engineers, consisting of Col. Amos Stickney, Maj. J. G. Warren, and Capt. H. H. Chittenden, Corps of Engineers, reported January 23, 1904, on the flood conditions of Kansas River in Kansas City. This report states that the normal average width of Kansas River through Kansas City, which was 850 feet, the minimum width having been 540 feet, has been reduced to an average width of 590 feet, the minimum width being 420 feet. The bridges have more piers than is necessary and are founded on piles. Between and around the piers are piles and loose rock that prevent the natural scour of the bed in time of flood. As a result of these encroachments on the river the natural channel capacity for carrying off floods has been reduced to about one-half.

The measures declared necessary to avert another disaster like that caused by the 1903 flood are to restore to the river in Kansas City a width of at least 734 feet; to construct masonry walls on each side reaching to an approximate height of 30 feet above low water for a distance of 17,000 feet above the mouth; to dredge the river bed of all solid obstructions to a depth of 15 feet below low water; to limit the number of piers to two, 300 feet apart, carried down to rock, and having the lowest part of the structure on them above the flood line of 1903, and to construct earth levees with paved slopes above the point where masonry walls are necessary, and carry these to the bluffs above Argentine and Armourdale.

Inasmuch as this improvement would be very expensive and require a long time to carry out, the board recommended the following measures as a minimum requirement under existing conditions:

(1) That further encroachments on the banks be stopped and existing encroachments be removed, so as to give the channel an average width of at least 600 feet for a distance of 17,000 feet above the mouth.

(2) That the channel be cleared of all obstructions to a depth of at least 15 feet below standard low water.

(3) That all bridge owners be required to remove obstructions around or between existing piers and to construct their bridges with only two piers, to be

carried down to rock and to be 300 feet apart, measured on a line perpendicular to the center line of the channel, the lowest point of the structure to be above the flood line of the ultimate channel.

Since the above was written the Kansas legislature has authorized the formation of drainage districts in Kansas. The directors of each district have control of all the streams in the district and provide for widening, deepening, and straightening the channel and the construction and maintenance of levees to prevent overflow. A district extending from above Argentine to the mouth of Kansas River has been organized, surveys are being made, plans and estimates prepared for the passage of a rate of flow of 160,000 second-feet without overflow. The United Zinc and Chemical Company in this district has already constructed a levee to protect its property at a cost of $15,000. The Armour Packing Company has also constructed a levee to protect its property.

FLOOD NEAR LAWRENCE, KANS.

From high-water marks above the dam at Lawrence it was found that the depth of water on the crest of the dam, measured at a point sufficiently far upstream to be out of the influence of the curvature of the surface near the crest, was 19.7 feet in the 1903 flood and 13.5 feet in that of 1904—that is, the crest of the former flood was about 6.2 feet higher than that of the latter. The high-water marks on the south side are about 9 inches higher than those on the north side, this being due to the bend in the stream. The 1903 flood cut a new channel about 400 feet wide and so deep that all the ordinary flow passed through it around the north end of the bridge. This channel was filled with rock in October, 1903, reducing the waterway to its former dimensions. The 1904 flood passed over the end of this fill and was prevented from cutting another new channel only by a levee of sand bags. About one-fourth mile farther north the river overflowed the Union Pacific Railway embankment, washed out several hundred feet of track, and submerged several hundred acres of low land in the vicinity of Lawrence. A part of the apron of the dam was washed out during this flood, and later a part of the dam itself and of the north abutment of the bridge.

Since the above was written the length of the crest of this dam has been increased about 65 feet, thus increasing the width of the channel about 11 per cent. The cost of this work, including a new abutment and truss for the bridge and the filling of the new channel cut by the flood of 1903, was $75,000.

FLOOD NEAR LECOMPTON, KANS.

Gage height and discharge.—The mean daily fluctuations of the surface of Kansas River at this place and the corresponding daily rate

of discharge during this flood, as shown by the United States Geological Survey gage on the highway bridge, and also the corresponding data for the flood of 1903 are as follows:

Gage height and discharge of Kansas River at Lecompton, Kans., May 25 to June 8, 1903, and June 24 to July 17, 1904.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1903.	*Feet.*	*Sec.-feet.*	1904.	*Feet.*	*Sec.-feet.*
May 25	14.15	80,075	June 28	12.00	41,040
May 26	12.15	55,500	June 29	10.70	32,670
May 27	16.60	99,500	June 30	10.05	28,600
May 28	18.00	113,500	July 1	11.10	35,150
May 29	21.10	144,500	July 2	9.60	26,450
May 30	24.00	173,500	July 3	8.70	21,920
May 31	[a] 28.75	221,000	July 4	8.45	20,500
June 1	27.20	205,500	July 5	10.10	29,160
June 2	26.25	196,500	July 6	16.75	91,040
June 3	26.35	197,500	July 7	20.75	130,000
June 4	24.35	177,500	July 8	18.75	110,000
June 5	23.05	164,500	July 9	16.45	87,120
June 6	20.50	138,500	July 10	14.55	70,060
June 7	18.20	115,500	July 11	13.15	57,720
June 8	16.50	98,500	July 12	12.10	48,760
1904.			July 13	11.40	43,560
June 24	6.15	11,530	July 14	11.00	40,700
June 25	10.50	31,460	July 15	10.50	37,230
June 26	14.70	59,800	July 16	9.55	31,390
June 27	13.70	52,800	July 17	8.95	27,800

[a] Maximum gage height, 29.50 feet.

It is seen that this flood lasted from July 5 to 15, reaching a maximum at about noon on July 7, with a gage reading of about 21 feet and an estimated discharge of about 130,000 cubic feet per second. The highest reading of this gage in 1903 was 29.5 feet, so that the crest of the 1903 flood was 8.5 feet higher than the crest of the 1904 flood at this place. The left bank was overflowed for a distance of about 300 feet in the 1904 flood, and a distance of at least one-half mile during the 1903 flood.

Fig. 6 shows graphically the change in volume with the time from the beginning of each of these floods, also the change in the volume for the flood of 1902. Each ordinate of this diagram represents volume of flow per second in thousand second-feet; each abscissa represents days from the beginning of the flood. The magnitude of

the 1903 flood, as compared with that of 1904 and 1902, is clearly seen.

The tables on pages 75 and 76 give the mean daily gage height and corresponding discharge of Blue River near Manhattan, and of Smoky Hill River at Ellsworth, during the flood of 1903, for comparison with the floods at those places in 1904.

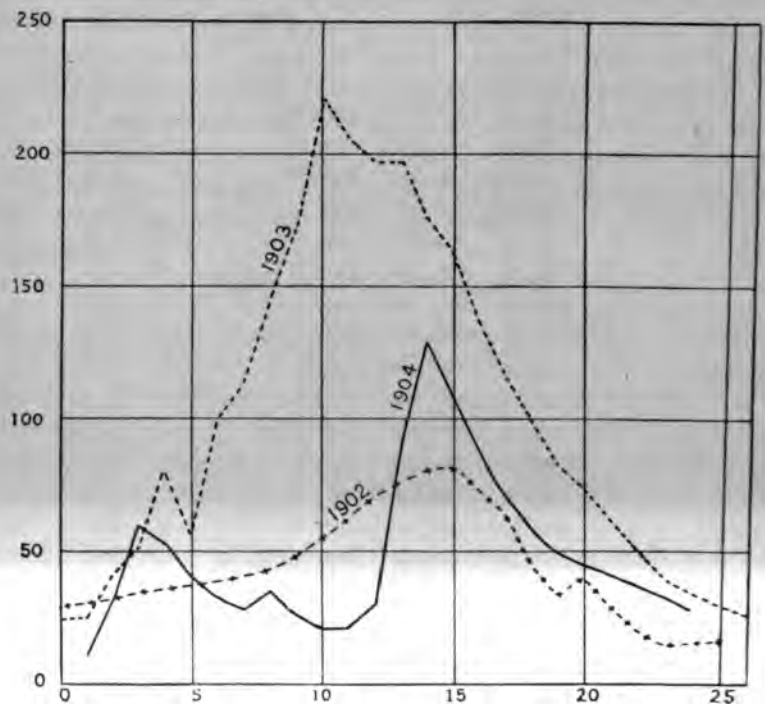


FIG. 6.—Flood discharge of Kansas River at Lecompton, Kans., in 1902, 1903, and 1904.

Necessary waterway.—The width of the channel between the abutments of the bridge at Lecompton is 800 feet. When the flood of June, 1903, was at its maximum stage the left bank was overflowed for a distance of at least one-half mile, but most of this overflow had very little velocity, and the discharge through the overflow part of the cross section was not more than 5 per cent of the total discharge. The right bank, along which are the Santa Fe Railway tracks, was submerged for a distance of about 110 feet.

The area of the water cross section at this station when the 1904 flood was at its highest stage was 17,830 square feet; the measured mean velocity was about 7.3 feet per second, and the mean depth was about 22 feet. By Kutter's formula it is possible to compute the mean velocity in a trapezoidal cross section, and thus by trial to determine the proper size of section to carry the flood of 1903 without too great surface elevation. In such a section of bottom width 750

feet, side slopes 1½ to 1, and depth of 22 feet, passing the 1904 flood with a surface slope of 1½ feet per mile and a coefficient of roughness n equaling 0.030, the mean velocity is found to be about 6.6 feet per second, 0.7 foot per second less than the mean measured velocity, indicating either a greater surface slope than 1½ feet per mile or a smaller value of n than 0.030, or both. If the slope is 2 feet per mile and the other data remain the same as before, the velocity becomes 7.4 feet per second, 0.1 second-foot greater than the observed velocity. It is not likely that the slope was greater than 2 feet per mile, hence the value of n was less than 0.030.

The next question is to determine what would have been the mean velocity in this assumed trapezoidal channel if all the water of the 1903 flood had flowed in it (without scour and without increase in surface elevation of the flood crest) with a mean depth of 30.8 feet, a surface slope of 2 feet per mile, and $n=0.025$. The total estimated discharge is 233,000 second-feet; area, 24,270 square feet; observed velocity, 9.6 feet per second. By the use of Kutter's formula the mean velocity of the water in the assumed trapezoidal section is found to be 10.2 feet per second. Hence this trapezoidal waterway with bottom width of 750 feet and top width of 842 feet would have carried the 1903 flood past this station if levees were built to prevent overflow, without any increase in elevation of the crest of the flood.

The following table gives the maximum and minimum discharge of the Kansas at Lawrence and Lecompton each year since 1891:

Maximum and minimum daily discharge of Kansas River at Lawrence,[a] Kans., 1891 to 1898, and at Lecompton,[b] Kans., 1899 to 1904.

Year.	Maximum discharge in second-feet.				Minimum discharge in second-feet.			
	Date.	Gage height.	From total drainage area.	Per square mile.	Date.	Gage height.	From total drainage area.	Per square mile.
1891	June	6.40	35,750	0.597	January	0.20	967	0.016
1892	May	9.20			September, October, and December.	.00	787	.013
1893	June and July.	4.60	21,440	.358	September and December.	.00	787	.013
1894	June	5.60	28,960	.484				
1895	August	5.50	28,190	.471				
1896	July	7.70	53,308	.891	January	.75	698	.012
1897	April	8.80	58,000	.969	December	1.70	562	.0094
1898	June	5.60	28,960	.484	do	2.25	507	.0085
1899	July	11.00	30,250	.517	October	1.90	1,750	.030
1900	March	10.20	24,898	.425	February	2.20	2,830	.048
1901	April	10.00	25,000	.427	July, August, and November.	2.00	275	.0047
1902	July	17.60	81,400	1.39	March	1.80	100	.0017
1903	May	28.75	221,000	3.77	October	3.00	2,375	.041
1904	July	20.75	130,000	2.22				

[a] Drainage basin 59,841 square miles. [b] Drainage basin 58,550 square miles.

FLOODS NEAR TOPEKA, KANS.

Gage height.—At the time of the July, 1904, flood there were three river gages at Topeka, two belonging to the United States Geological Survey and one belonging to the Wolff Packing Company. One of the United States gages was on a pier of the Rock Island Railway bridge and the other was on a pier of the Santa Fe Railway bridge. Each consisted of foot and tenth marks painted on the side of a pier. The Wolff Packing Company gage consisted of a vertical timber marked to feet and tenths and fastened to the right bank of the river near their packing house. The location of these gages is shown in fig. 8. The readings of the Wolff gage are given on page 62. The readings of the United States gage on the Rock Island Railway bridge are given below.

Gage height, in feet, of Kansas River at North Topeka, Kans., May 28 to June 10, and June 25 to July 20, 1904.

Date.	Time.	Gage height.	Date.	Time.	Gage height.
		Feet.			*Feet.*
May 28	7.45 a. m	6.7	June 9	1.30 p. m	9.4
	1.30 p. m	6.55	June 10	7.45 a. m	9.7
May 29	7.30 a. m	11.2		1.30 p. m	10.3
	2 p. m	13.5	June 25	7.45 a. m	11.3
May 30	5 a. m	18.0		1.30 p. m	12.8
	1.30 p. m	17.1	June 26	8.15 a. m	17.1
May 31	7.45 a. m	12.8		3 p. m	16.6
	1.30 p. m	11.95	June 27	8.15 a. m	15.9
June 1	7.45 a. m	10.8		2 p. m	15.5
	1.30 p. m	10.5	June 28	8 a. m	14.1
June 2	7.45 a. m	11.4	June 29	7.45 a. m	12.7
	1.30 p. m	11.8	June 30	7.45 a. m	11.7
June 3	7.45 a. m	12.2	July 1	7.45 a. m	13.2
	1.30 p. m	12.2	July 2	8 a. m	11.7
June 4	7.45 a. m	12.6	July 3	8 a. m	10.3
	1.30 p. m	12.1	July 4	9.45 a. m	10.5
June 5	8.15 a. m	12.7	July 5	7.45 a. m	10.5
	2.20 p. m	12.8	July 6	7 a. m	16.1
June 6	7.45 a. m	12.5		1.30 p. m	18.5
	1.30 p. m	12.2	July 7	6 a. m	22.3
June 7	7.45 a. m	11.1		7 p. m	21.8
	1.30 p. m	10.1	July 8	7.45 a. m	19.8
June 8	7.45 a. m	10.1		5.30 p. m	19.0
	1.30 p. m	10.0	July 9	7 a. m	18.9
June 9	7.45 a. m	9.1		5 p. m	18.3

Gage height, in feet, of Kansas River at North Topeka, Kans., 1904—Continued.

Date.	Time.	Gage height.	Date.	Time.	Gage height.
		Feet.			*Feet.*
July 10	7 a. m	17.4	July 15	7.45 a. m	12.9
	5 p. m	17.0		2 p. m	12.7
July 11	7.30 a. m	16.7	July 16	7.45 a. m	12.2
	5 p. m	16.0		2 p. m	12.0
July 12	7 a. m	14.0	July 17	9 a. m	11.6
	5 p. m	14.0		3 p. m	11.2
July 13	7.45 a. m	13.7	July 18	7.45 a. m	10.9
	1.30 p. m	13.8		2 p. m	10.5
July 14	7.45 a. m	13.7	July 19	7.45 a. m	9.7
	2 p. m	13.7	July 20	7.45 a. m	8.6

The flood reached its height on July 7, for a reading of about 22.3 feet,[a] or about 17.8 feet above low water. The elevation of the high-water mark of 1903 on the engine room of the Wolff Packing Company is 902.63 feet and of the 1904 flood 896.44 feet, so that the high water of 1903 was about 6.2 feet higher than the high water of 1904 at this place. The former flood came to the top of the rail of the Santa Fe Railway bridge and was about 43 inches in depth on the rail of the Rock Island Railway bridge. The latter flood reached the under surface of the Rock Island Bridge and took out the false works of one span. There was therefore a difference of only 6.2 feet in the elevation of the crest of these floods at Topeka, whereas there was a difference in elevation of the crest at Lecompton of 8.5 feet.

Obstructions in channel.—During the flood in 1904 two cableways that had been used for lifting sand from the bed of the river were in the river bed with the ends fastened to the trees on shore; these collected drift and retarded the flow. Some distance farther downstream was a Melan arch bridge, with its large piers and small, low arches, in front of which large quantities of drift collected. A few feet above this bridge were the ruins of a pile bridge destroyed by the 1903 flood, and about 50 feet below was a second pile bridge, the bents of which were 30 feet apart. These three bridges so near together and of such small, short spans collected the drift and formed a dam. The Melan bridge (fig. 7) has 5 arches, the central one having a span of 124 feet, the two adjacent spans of 110 feet, and the other two spans of 96 feet. The waterway below the spring lines of these arches was about 9,600[b] square feet. This is only about 40 per cent of the

[a] This reading may be in error one or two tenths of a foot on account of its being impossible for the reader to get near the gage, one span of the bridge having washed out.

[b] Result based on soundings taken July 19, 1904.

smallest area found necessary to pass the 1903 flood at Lecompton, and only 56 per cent of the waterway necessary to pass the 1904

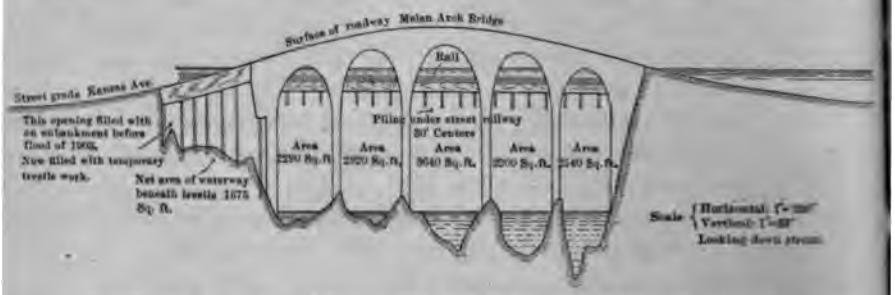


FIG. 7.—Cross section of Kansas River at Melan arch bridge, Topeka, Kans.

flood. It is little wonder that the left abutment of this bridge was washed out in the 1903 flood, as shown in Pl. VI, *A*, and a

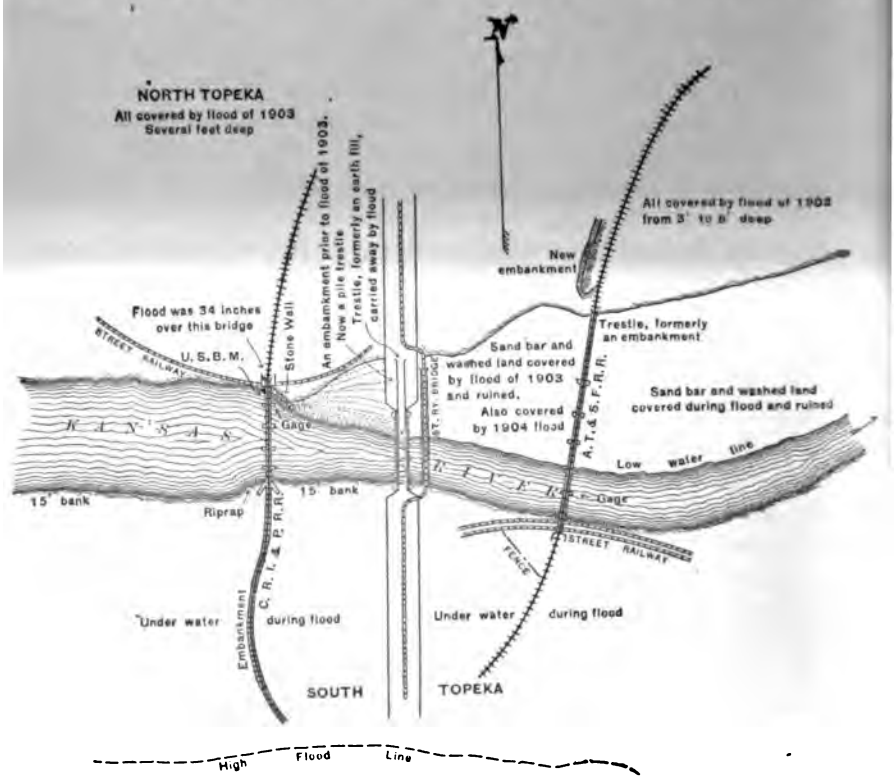


FIG. 8.—Kansas River and flooded area in vicinity of Melan arch bridge, Topeka, Kans.

very large area of the city flooded. It seems almost incredible that this city should have allowed a pile bridge to be built in this already restricted part of the channel, and especially should have allowed a

A. CHANNEL SCOURED BY KANSAS RIVER AROUND THE ABUTMENT OF THE MELAN BRIDGE, TOPEKA, KANS.

B. RUINS OF DENVER AND RIO GRANDE RAILWAY BRIDGE, TRINIDAD, COLO.

second one to be built at this place after the complete destruction of the old pile bridge and of part of the Melan bridge.[a]

Fig. 8 shows the location of the bridges and gages at Topeka, a part of the flooded area, and depth of overflow. Topeka, like Lawrence, is located in a bend of the river, and during great floods the river cuts across these bends and floods large areas of lowland.

FLOOD NEAR MANHATTAN, KANS.

The daily gage heights and corresponding discharge of Blue River near Manhattan, Kans., during the flood of 1904 and also during that of 1903 are given in the table on page 75. It would seem that the flood reached its maximum stage on July 6 for a gage height of 22.8 feet and the discharge of 23,160 second-feet. This stage is 13 feet less and the discharge only about one-third of that during the 1903 flood at this place.

FLOOD NEAR JUNCTION, KANS.

The following readings of the United States Geological Survey gage on the highway bridge over Republican River at Junction show the fluctuations of the surface of this river during the June and July floods of 1904.

Gage height, in feet, of Republican River at Junction, Kans., June 14 to July 11, 1904.

[Gage at highway bridge near pump house.]

Date.	9 a. m.	4 p. m.	Date.	9 a. m.	4 p. m.
June 14	4.8	4.75	June 28	9.2	8.8
June 15	4.4	8.6	June 29	7.9	7.6
June 16	10.7	10.4	June 30	7.6	7.2
June 17	8.9	8.4	July 1	6.7	6.4
June 18	7.3	6.8	July 2	6.1	6.0
June 19	6.4	5.8	July 3	5.7	5.7
June 20	5.4	5.5	July 4	7.0	6.7
June 21	5.6	5.7	July 5	10.8	10.5
June 22	6.0	6.1	July 6	10.0	9.8
June 23	6.1	5.7	July 7	10.5	10.4
June 24	5.5	5.6	July 8	10.1	9.1
June 25	11.8	12.3	July 9	7.7	7.4
June 26	13.0	12.7	July 10	7.7	7.4
June 27	11.4	10.5	July 11	6.4	6.4

[a] Since the above was written two arches have been added to the Melan steel-concrete arch bridge, thus increasing the channel width about 150 feet. The street-car bridge supported on piles has been replaced by a steel bridge supported on metal piers placed directly back of the piers of the Melan bridge. Levees are being built along the Kansas River and Soldier Creek to prevent overflow.

These readings show that the highest water in July occurred on the 5th, the gage height being 10.8 feet, or about 7.4 feet less than the highest reading at this place in 1903. The June flood of 1904 was greater at this station than the July flood, the maximum gage reading being 13 feet on June 26, as compared with 10.8 feet on July 5. The flood of 1903 cut a shallow channel around the left approach to this bridge. The June flood of 1904 widened and deepened this new channel so that in August, 1904, it was about 180 feet wide and nearly as deep as the main channel. The flow in this new channel enters the main channel a short distance below the station, and has a marked retarding effect on the flow in the main channel.

The July flood on Smoky Hill River at Junction was much larger than that on Republican River. There is no gage on the Smoky Hill at this place, but from the high-water marks in Mr. Hogan's mill it is found that the crest of the July flood of 1904 was only 5 inches less than the crest of the flood in 1903. Nearly as much damage was done by the 1904 flood as by the earlier one, the water in 1904 appearing to have a greater velocity and a greater scouring effect than that of the 1903 flood. The macadamized road from the city to this mill was badly damaged by the scour.

FLOOD NEAR SOLOMON, KANS.

Fluctuations of the water surface at Solomon are shown by the following readings of the United States Geological Survey gage:

Gage height on Smoky Hill River at Solomon, Kans., June and July, 1904.

Date.	Time.	Gage height.	Date.	Time.	Gage height.
		Feet.			*Feet.*
June 4	8 a. m.	15.5	June 30	7 p. m.	15.1
	7 p. m.	17.4	July 5	10 a. m.	16.9
June 5	10 a. m.	18.9	July 6	11 a. m.	21.8
	7 p. m.	19.8		8.30 p. m.	23.9
June 6	9.30 a. m.	21.1	July 7	7.30 a. m.	25.4
	7.30 p. m.	22.0		6 p. m.	26.4
June 7	6 a. m.	22.6	July 8	8.30 a. m.	27.0
	7.30 p. m.	22.7		8 p. m.	27.5
June 8	11 a. m.	20.6	July 9	9 a. m.	27.8
June 26	11.30 a. m.	19.5		5 p. m.	27.8
	8 p. m.	21.6	July 10	11 a. m.	27.9
June 27	7.30 a. m.	23.3		8 p. m.	27.9
	7 p. m.	23.6	July 11	8 a. m.	27.9
June 28	8 a. m.	23.0		6.30 p. m.	27.9
	8 p. m.	22.1	July 12	6.30 a. m.	27.7
June 29	7.30 a. m.	20.7	July 13	7 a. m.	26.9
	8 p. m.	19.3	July 14	11 a. m.	25.0
June 30	7 a. m.	15.6	July 15	11 a. m.	21.8

The above records show that there were two rises in this river in June—one that reached a maximum on June 7, with a gage height of 22.7 feet, and the other that reached a maximum on June 27, with a gage height of 23.6 feet. The July flood reached its maximum on July 10, for a gage height of 27.9 feet. The highest gage reading at this place in 1903 was 32.5 feet—that is, 4.6 feet higher than the highest reading in 1904. The high water of 1904 only covered the highest bottom lands and did little damage as compared with that of 1903. This high water came mainly from Smoky and Saline rivers, Solomon River not being especially high.

COMPARISON OF FLOODS OF 1903 AND 1904.

From the table on page 67 and fig. 6, page 68, it is seen that Kansas River was flowing at a rate of 98,000 cubic feet per second or more for thirteen consecutive days in 1903, and the discharge was greater than this on only two consecutive days in 1904. The maximum daily rate of discharge in 1903 was about 70 per cent greater than that in 1904. The total volume discharged by the river for the thirteen days when the flow was greatest in 1903 was two and one-half times more than for the thirteen days of greatest flow in 1904.

Gage height and discharge of Blue River near Manhattan, Kans., May 25 to June 8, 1903, and June 24 to July 17, 1904.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1903.	*Feet.*	*Sec.-feet.*	1904.	*Feet.*	*Sec.-feet.*
May 25	27.50	46,670	June 28	11.90	7,020
May 26	25.00	40,170	June 29	10.10	4,800
May 27	30.50	54,470	June 30	15.60	12,360
May 28	32.00	58,370	July 1	14.60	10,860
May 29	[a] 33.50	62,270	July 2	10.40	5,150
May 30	[a] 34.80	65,650	July 3	9.10	3,730
May 31	[a] 36.00	68,770	July 4	10.60	5,380
June 1	[a] 35.00	66,170	July 5	12.60	7,980
June 2	[a] 33.80	63,050	July 6	22.80	23,160
June 3	32.50	59,670	July 7	19.90	18,810
June 4	30.00	53,170	July 8	17.90	15,810
June 5	27.00	45,370	July 9	16.00	12,960
June 6	25.50	41,470	July 10	14.80	11,160
June 7	21.50	23,900	July 11	13.40	9,100
June 8	17.50	15,900	July 12	12.40	7,700
1904.			July 13	12.70	8,120
June 24	8.30	2,970	July 14	11.40	6,360
June 25	15.20	11,660	July 15	10.50	5,260
June 26	15.10	11,510	July 16	9.80	4,470
June 27	12.50	7,840	July 17	9.50	4,140

[a] Maximum gage height, 36.50 feet.

From the preceding table it can be seen that the Blue, near Manhattan, was discharging at the rate of 40,000 second-feet or more for thirteen consecutive days in 1903, while at no time during the flood of 1904 was the flow of this river 24,000 cubic feet per second. The maximum daily rate in 1903 was 68,770 second-feet, and in 1904 it was 23,160 second-feet.

The Smoky Hill at Ellsworth had a maximum daily flow of more than 3,000 second-feet on six days in 1903, but reached that amount on only three days in 1904.

Gage height and discharge of Smoky Hill River at Ellsworth, Kans., May 25 to June 8, 1903, and June 24 to July 16, 1904.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1903.	*Feet.*	*Sec.-feet.*	1904.	*Feet.*	*Sec.-feet.*
May 25	3.00	557	June 28	1.70	110
May 26	5.00	1,835	June 29	2.30	271
May 27	3.30	710	June 30	2.20	239
May 28	15.40	10,866	July 1	5.50	2,205
May 29	16.00	11,392	July 2	7.60	3,920
May 30	13.80	9,466	July 3	4.30	1,440
May 31	10.20	6,130	July 4	3.60	883
June 1	7.70	4,005	July 5	2.70	422
June 2	7.00	3,410	July 6	10.40	6,300
June 3	5.40	2,129	July 7	6.60	3,075
June 4	4.80	1,690	July 8	4.40	1,410
June 5	4.40	1,410	July 9	4.80	1,690
June 6	4.30	1,342	July 10	4.00	1,141
June 7	3.90	1,075	July 11	3.40	765
June 8	3.60	883	July 12	3.10	607
1904.			July 13	2.90	510
June 24	1.40	62	July 14	1.70	110
June 25	3.30	709	July 15	1.50	76
June 26	2.15	224	July 16	1.35	56
June 27	1.90	155			

DAMAGE DONE BY FLOOD.

The damage caused by the 1904 flood along Kansas River was very much less than by the flood of 1903. This was due to three causes: First, the flood height was from 5 to 8 feet greater in the 1903 flood than in that of 1904, and consequently the area submerged was very much greater. The areas submerged in Kansas City during these floods are shown in Pl. V (p. 64). Second, the property in the over-

flow area, especially in the cities, was less in 1904 than in 1903. Only a few of the buildings that were swept away or destroyed by the 1903 flood were replaced. Third, the people living along this stream heeded promptly the warnings of the approach of a flood issued by the United States Weather Bureau in 1904 and conveyed movable property out of reach of the waters.

The crops on the low land along the river were destroyed, and the lateness of the flood prevented the maturing of a second crop; in this respect the 1904 flood was more injurious to farmers than that of 1903. Some of the best corn raised in Kansas in 1903 was raised on the bottom land along the Kansas that was overflowed in the May flood of that year.

Very few bridges were destroyed in the 1904 flood, and the damage to railroads along this river was comparatively small. J. C. Bye, resident engineer of the Union Pacific Railroad at Kansas City, stated to the writer that the loss sustained by the Union Pacific Railroad Company along this river was about $1,250,000 in the 1903 flood and about $75,000 in the 1904 flood, or only about 6 per cent of the former. This percentage probably represents approximately the losses of the other railroads doing business in Kansas River Valley during these floods.

The loss, risk, and inconvenience suffered by the cities and towns along the river for lack of water for drinking and fire purposes, and the lack of illuminating gas, electric light, and power was very small during the 1904 flood as compared with that of 1903.

PREVENTION OF FUTURE DAMAGE.

The remedy for overflow and damage resulting therefrom along this river, as stated in the flood report in 1903, is the rapid removal of the flood water from the drainage basin and the protection by levees of the lowlands from overflow. The natural width of the river of about 850 feet has been reduced to 600 feet in many places, and in one place to 420 feet; that is, by more than 50 per cent of its width. The bridges are constructed on piers founded on piles with rock filling around them that prevent the natural deepening of the channel during a flood. A greater number of piers are used than is necessary, and against these piers drift collects, forming a dam that retards the flow of the stream and causes overflow of the lowlands. The channel in places, notably Kansas City and Topeka, is more or less clogged with wreckage.

The measures declared necessary by the board of army engineers for preventing the recurrence of another flood of the magnitude of

that in 1903 (see pp. 65–66) are expensive. Many important industries have been allowed to locate on the banks of this river and encroach in its natural width. To condemn land on each side of the stream in the cities sufficient to restore to the stream its natural width would destroy these industries. The building of masonry walls on each side of the stream through Kansas City and the necessary elevation of bridges to the height of these walls will necessitate the raising of all the railroads in the low part of Kansas City and will be very expensive.

Instead of widening the channel to its original dimensions it is suggested that an overflow channel be constructed to carry the flood waters past Kansas City. This, however, is simply a detail. The remedy for overflow is sufficiently clear, namely, an additional waterway sufficient to carry off floods. The most satisfactory and economical means of securing this additional waterway is a local problem that requires much study.

NEOSHO RIVER FLOODS.

The 1904 floods on Neosho River were greater in number, height, and destructiveness than ever known before on this stream. The flood of 1885 was the largest prior to that of 1904. Although there are no definite records of the height reached by the 1904 flood, there are quite a number of well-defined flood marks along the river, which show that the crest of the flood of July 10, 1904, reached a height of about 1 foot greater than that of the 1885 flood.

STREAMS AND DRAINAGE BASIN.

Neosho River rises in the northern part of Morris County, Kans., flows in a southeasterly and southerly direction through Kansas and Indian Territory, and empties into Arkansas River near Fort Gibson, Ind. T. In a direct course this river has a length of about 260 miles, but the distance along the bed is much greater, as this is very crooked. It falls, in a distance of about 136 miles, from an elevation of about 1,500 feet near its source to 800 feet at a point about 27 miles north of the Kansas-Indian Territory line, and from this point to the mouth, a distance of 110 miles in a straight line, it falls about 300 feet. It drains a long, narrow stretch of land just east of Verdigris River and west of Osage and White rivers. A profile of the river obtained from the atlas sheets of the United States Geological Survey is as follows:[a]

[a] Water-Sup. and Irr. Paper No. 44, U. S. Geol. Survey, 1901, p. 66.

Elevations on Neosho River.

Locality.	Distance from mouth in miles.	Height above sea in feet.	Fall per mile in feet.
Mouth	0	470	.....
	12	500	2.5
Markham Ferry, Ind. T.	42	550	1.7
	69	600	1.8
Above Oswego, Kans	177	800	1.8
	206	850	1.7
Humboldt, Kans	228	900	2.3
Leroy, Kans	255	950	1.8
Ottumwa, Kans	274	1,000	2.6
Emporia, Kans	296	1,050	2.3
	310	1,100	3.6
Council Grove, Kans	326	1,200	6.25
Head	346	1,500	15.0

As compared with the Verdigris, Neosho River rises about 40 miles farther north and at about 100 feet greater elevation. They flow in nearly parallel directions and empty into Arkansas River only a few hundred feet apart. The Verdigris falls more rapidly in its upper course than the Neosho, reaching the State line at an elevation of 680 feet, falling 720 feet in about 151 miles. The Neosho falls more gradually, reaching the State line at an elevation of about 770 feet, falling 730 feet in about 267 miles. From the State line the Neosho falls about 270 feet and the Verdigris about 180. As a result of these differences in the topography of the watershed, the Verdigris flows in a narrow, deep channel while the Neosho is wider, has lower banks, and is subject to overflow in many places, notably near Chanute, Kans. Near the mouth the differences are more marked. The Verdigris is deeper, 250 feet wide, and sluggish, with scarcely a perceptible current at ordinary stage of water. The Neosho is from 600 to 800 feet wide, is shallow, and has a fairly rapid velocity.

The principal tributaries of the Neosho are the Cottonwood, which enters it from the west near Emporia, and Spring River, which enters it from the east a little south of the Kansas line.

The area of land flooded along this river is large compared with the size of the stream. This, in fact, is true of all the streams in the southeastern part of Kansas. They have little fall and are very crooked. The water, instead of running off quickly, is held

back, overflows the banks, spreads out over the river bottom to a width in places of from 4 to 5 miles. The average fall of the stream from Emporia to the mouth is less than 2 feet per mile, and there are stretches of 20 miles where the fall is only 1.7 feet per mile.

FIG. 9.—Drainage basins of southeastern Kansas.

There are stretches of 10 miles where the river is so crooked that the length, measured along the river, is more than twice that in a direct course. These numerous bends, together with the trees that grow thickly to the water's edge in some places, reduce the already

small slope of the stream so much that its effective value is probably not more than 1¼ feet per mile.

The upper part of the watershed is hilly pasture land, from which the water flows rapidly. The central and lower part is rolling cultivated land. There are no forests on the watershed, but narrow strips of trees are found along the greater part of the stream.

DISCHARGE AND RUN-OFF.

A gaging station was established on this stream August 1, 1895, at a highway bridge about 1 mile west of Iola, a short distance below a dam. The channel is straight for several hundred feet above and below the station, and the bed, though stony, is quite permanent. Both banks are low and subject to overflow during flood, especially the right one. The following table gives the maximum and minimum gage height and corresponding discharge for the years—1896 to 1903—that this station was in operation. The maximum flow is seen to be very large and the minimum flow very small. For sixty days in 1896 and for one hundred and twenty days in 1897 the stream was almost dry, the discharge being only 1 cubic foot per second.

Estimated monthly discharge of Neosho River at Iola, Kans.

[Drainage area, 3,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	275	100	125	7,686	0.03	0.03
February	275	75	114	6,557	.03	.03
March	125	20	61	3,751	.02	.02
April	15,025	50	2,708	161,137	.82	.74
May	45,560	160	10,273	631,666	3.23	2.80
June	5,048	250	905	53,851	.28	.25
July	7,890	125	1,278	78,581	.40	.35
August	300	10	58	3,566	.02	.02
September	10	0	6	357	.002	.002
October	225	0	11	676	.003	.003
November	2,290	5	245	14,578	.07	.07
December	445	20	88	5,411	.02	.02
The year	45,560	0	1,322	967,817	4.925	.36

Estimated monthly discharge of Neosho River at Iola, Kans.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	920	105	531	32,650	0.167	0.145
February	3,970	395	1,689	93,802	.479	.419
March	4,840	340	960	59,030	.302	.262
April	2,183	395	894	53,197	.272	.238
May	665	170	379	23,305	.119	.103
June	1,445	75	363	21,600	.110	.096
July	422	87	163	10,023	.051	.044
August	87	50	72	4,427	.023	.020
September	62	1	9	536	.002	.002
October	1	0	1	62	.000	.000
November	1	1	1	60	.000	.000
December	1	1	1	62	.000	.000
The year	4,840	0	422	298,754	1.525	.115
1898.						
January	50	1	7	430	.002	.002
February	5,060	1	466	25,881	.146	.127
March	7,077	80	692	42,550	.218	.188
April	5,460	220	753	44,807	.237	.205
May	26,225	1,250	8,855	544,476	2.785	2.413
June	27,875	1,250	5,360	318,941	1.686	1.461
July	1,050	180	392	24,103	.123	.107
August	1,825	110	543	33,388	.171	.148
September	5,220	110	678	40,344	.213	.185
October	3,620	50	395	24,288	.124	.108
November	3,695	145	482	28,681	.152	.131
December	16,077	305	2,311	142,099	.727	.629
The year	27,875	1	1,745	1,269,988	6.584	.475

timated monthly discharge of Neosho River at Iola, Kans.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1899.						
ry	450	305	357	21,951	0.12	0.10
ary	4,020	220	617	34,266	.18	.17
ı	12,290	780	2,138	131,461	.67	.58
	1,825	505	887	52,780	.27	.24
	5,620	282	1,094	67,268	.35	.30
	22,191	350	4,168	248,013	1.27	1.14
	21,365	305	3,443	211,703	1.08	.94
st	630	220	308	18,938	.09	.08
nber	305	180	200	11,901	.06	.05
er	145	50	98	6,026	.03	.03
nber	50	50	50	2,975	.01	.01
ıber	110	50	75	4,612	.02	.02
The year	22,191	50	1,120	811,894	4.15	.31
1900.						
ıry	192	145	179	11,006	.06	.05
ary	292	192	200	11,107	.05	.05
ı	10,412	292	2,604	160,114	.82	.71
	9,800	338	2,229	132,635	.68	.61
	23,700	385	4,098	251,976	1.29	1.12
	4,725	256	1,061	63,134	.32	.29
	4,025	292	766	47,099	.24	.21
st	650	145	201	12,359	.06	.05
nber	15,350	145	2,025	120,496	.61	.55
er	13,950	338	2,019	124,143	.63	.55
nber	30,411	510	3,418	203,385	1.04	.93
nber	650	292	382	23,488	.12	.10
The year	30,411	145	1,598	1,160,942	5.92	.43

Estimated monthly discharge of Neosho River at Iola, Kans.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1901.						
January	985	353	444	27,300	0.140	0.121
February	3,570	353	1,224	67,978	.348	.334
March	1,900	552	999	61,426	.314	.272
April	19,250	1,382	6,969	414,684	2.119	1.899
May	1,500	678	1,065	65,484	.334	.290
June	4,250	450	955	56,826	.290	.260
July	353	190	254	15,618	.080	.069
August	190	154	178	10,945	.055	.048
September	142	58	102	6,069	.031	.028
October	58	10	33	2,029	.010	.009
November	70	10	32	1,904	.010	.009
December	94	10	35	2,152	.012	.010
The year	19,250	10	102	732,415	3.743	.279
1902.						
January	467	190	370	22,750	.12	.10
February	1,000	445	549	30,470	.16	.15
March	1,400	445	601	36,954	.18	.16
April	4,900	490	836	49,745	.26	.23
May	18,500	490	5,585	343,408	1.75	1.52
June	35,550	2,000	11,694	695,841	3.56	3.19
July	6,690	925	2,169	133,367	.68	.59
August	24,550	330	6,382	392,414	2.01	1.74
September	18,500	580	4,962	295,259	1.51	1.35
October	20,150	850	4,689	288,315	1.48	1.28
November	2,600	580	1,119	66,585	.33	.30
December	7,500	925	2,227	136,933	.70	.61
The year	35,550	190	3,432	2,492,041	12.74	.94

Estimated monthly discharge of Neosho River at Iola, Kans.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1903.						
January	770	530	646	39,721	0.21	0.18
February	8,490	350	1,041	57,814	.29	.28
March	9,390	770	2,109	135,211	.69	.60
April	11,634	580	2,208	131,385	.67	.60
May	29,670	580	9,157	563,042	2.88	2.50
June	39,120	1,190	10,725	638,182	3.26	2.92
July	3,990	700	1,123	69,051	.36	.31
August	19,210	630	6,112	375,812	1.91	1.66
September	14,010	120	1,396	83,068	.42	.38
October	14,220	120	1,974	121,376	.62	.54
November	19,210	700	4,246	252,654	1.29	1.16

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 115; discharge measurements, page 116; rating table, page 117.

Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 267; rating table in Paper No. 39, page 450.

Gage heights and discharge measurements for 1900 are given in Water-Supply Paper No. 50, page 332; rating table in Paper No. 52, page 518.

Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

FLOOD NEAR IOLA, KANS.

Flood-gaging stations were established on this stream at Neosho Rapids and Humboldt by the United States Geological Survey and at Iola by the United States Weather Bureau in the spring of 1904. From the gage readings at these places the duration and magnitude of the floods on this river can be seen. The gage at Iola is just above a dam and does not show the same range of stage as did the old United States Geological Survey gage, which was just below this dam. The highest reading in 1903 was 13 feet 8 inches on July 4. The highest reading in 1904 was 15.2 feet on July 10. From the high-water marks at the bridge it appears that the reading of the old United States Geological Survey gage on July 10, 1904, was about 24 feet, or 22 feet above ordinary low water. The tables following give the gage readings and discharges at Iola.

Maximum and minimum discharge of Neosho River at Iola, Kans.

[Drainage basin, 3,670 square miles.]

Year.	Date.	Gage height in feet.	Maximum discharge in second-feet.		Date.	Gage height in feet.	Minimum discharge in second-feet.	
			From total drainage area.	Per square mile.			From total drainage area.	Per square mile.
1895	Sept. 12	21.00	.....	.....	October	2.03	.....	.....
1896	May 24	21.10	45,560	12.4	September and October.	2.00	0	0
1897	Mar. 5	6.35	4,840	1.32	October	1.70	0	0
1898	June 27	20.50	27,875	7.60	January and February.	1.80	1	0.00027
1899	June 9	17.03	22,191	6.05	October and December.	2.00	50	.014
1900	Nov. 2	18.95	30,411	8.29	January, August, and September.	2.10	145	.040
1901	Apr. 17	13.30	19,250	5.25	October and December.	.50	10	.0027
1902	June 11	21.25	[a]35,550	9.69	January	2.00	190	.052
1903	June 3	22.00	[a]39,120	10.7	September and October.	2.00	120	.033
1904	July 10	24.00	74,600	20.33	.....	.....	.....	.....

[a] Probably too small on account of overflow of banks.

Mean daily gage height of Neosho River at Iola, Kans., July 1–20, 1904.

[Weather Bureau record.]

Date.	Height in feet.	Date.	Height in feet.
July 1	11.4	July 11	14.7
July 2	9.5	July 12	14.0
July 3	3.7	July 13	13.2
July 4	4.2	July 14	13.0
July 5	4.2	July 15	12.6
July 6	11.0	July 16	10.5
July 7	12.6	July 17	3.3
July 8	13.8	July 18	2.9
July 9	14.96	July 19	2.2
July 10	15.2	July 20	1.8

The gage readings show that the flood at Iola lasted from July 6 to 16, and reached a maximum stage of 15.2 feet on July 10 for an estimated discharge of about 74,600 cubic feet per second, 34,600 cubic feet of which was overflow. This estimate of the discharge is necessarily very roughly approximated, as no measurements of *velocity* were made. It was necessary to estimate the velocity of

erflow from the amount of scour on the roadbed of the Mis-
Pacific Railway. This railroad crosses the valley on an em-
ent. The flood passed over this embankment on both sides
river and had a width of about 1½ miles on the right bank
vidth of about one-half mile on the left bank. The maximum
from actual measurement of the water above the surface of
l, was 4 feet at the deepest place. The stone ballast of the
as badly washed out in places, and the track was saved from
g away only by being held down. Trains could not cross
er for several days and passengers were taken across in boats.

FLOOD NEAR HUMBOLDT, KANS.

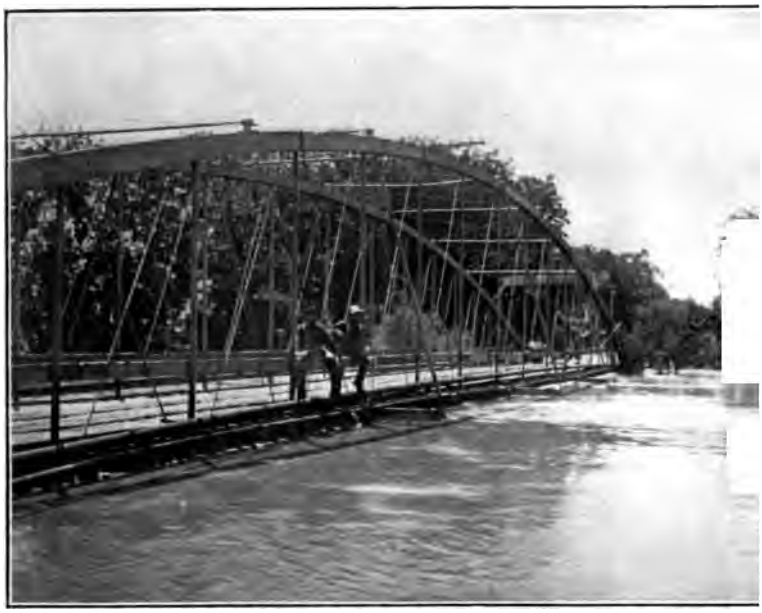
ood-gaging station was established at the highway bridge at
ldt in April, 1904. The fluctuations of the surface, measured
chain gage, are given below:

ight, in feet, of Neosho River at Humboldt, Kans., April 23 to 25 and May 6 to July, 1904.

ate.	Time.	Height.	Date.	Time.	Height.
		Feet.			*Feet.*
.....	5 p. m.	3	May 27	7 a. m.	9
.....	6.10 a. m.	25.1		8 p. m.	10
	8.25 a. m.	25.5	May 28	8 a. m.	11
	6 p. m.	27.2		7.10 p. m.	11.9
.....	1 a. m.	27.3	May 29	10 a. m.	11
	3 a. m.	27		8 p. m.	10.9
	7 p. m.	20	May 30	10.40 a. m.	15.7
	1 p. m.	25.7		8 p. m.	18
.....	6 p. m.	11	May 31	6.30 a. m.	19
.....	7 p. m.	13		10 p. m.	19.9
.....	10.30 a. m.	11.9	June 1	7 a. m.	20.4
.....	1.30 p. m.	13.2		7.30 p. m.	21.6
	5.30 p. m.	15	June 2	8 a. m.	22.4
.....	7.30 a. m.	18.5		6 p. m.	23.5
	6 p. m.	19	June 3	8.45 a. m.	27.7
.....	7 a. m.	18		7 p. m.	28.6
	6 p. m.	18	June 4	9 a. m.	29
.....	7 a. m.	17.4		7 p. m.	28.8
	8 p. m.	16.2	June 5	9 a. m.	28.2
.....	7 a. m.	16.2		6 p. m.	27
	8 p. m.	15.1	June 6	6 a. m.	26.5
.....	9 a. m.	10		7 p. m.	28.1
	8 p. m.	5	June 7	6 a. m.	28.5
.....	11 p. m.	4		8 p. m.	28.1
.....	7 a. m.	16.9	June 8	7 a. m.	27.7
	2 p. m.	13.5		7 p. m.	27.1

Gage height, in feet, of Neosho River at Humboldt, Kans., April 23 to 25 and May 6 to July, 1904—Continued.

Date.	Time.	Height.	Date.	Time.	Height.
		Feet.			*Feet.*
June 9	6.30 a.m.	26.2	June 29	7 p. m.	23.3
	7.30 p.m.	25.7	June 30	7 a. m.	23.3
June 10	7 a. m.	24.8		7 p. m.	22.9
	6 p. m.	24.2	July 1	8 a. m.	22.9
June 11	6.30 a.m.	21.7		7 p. m.	22.7
	7 p. m.	15	July 2	8 a. m.	22.3
June 12	6 a. m.	12.5		7 p. m.	21.3
	7 p. m.	14	July 3	7 a. m.	17
June 13	6 a. m.	15		7.30 p.m.	10.8
	7 p. m.	16.4	July 4	7.30 a.m.	11.3
June 14	7 a. m.	17		6.30 p.m.	12
	7 p. m.	17.2	July 5	7 a. m.	12.4
June 15	6 a. m.	15		6 p. m.	14.3
	6 p. m.	11.3	July 6	8 a. m.	23.9
June 16	6 a. m.	14		8.30 p.m.	24.5
	7 p. m.	17.5	July 7	10 a. m.	26
June 17	7 a. m.	18.3		7.30 p.m.	27.5
	7 p. m.	17.7	July 8	8 a. m.	28.7
June 18	6 a. m.	14.5		7 p. m.	28.3
	7 p. m.	11.9	July 9	2 a. m.	28.7
June 19	7 a. m.	11.9		12 m	29
	8 p. m.	13.7		9 p. m.	30
June 20	7.30 a.m.	14.5	July 10	8 a. m.	30.3
	8 p. m.	15.7		7 p. m.	30.7
June 21	6 a. m.	16	July 11	8 a. m.	30
	7 p. m.	15.8		8 p. m.	29.5
June 22	6 a. m.	15.4	July 12	7 a. m.	28.9
	8.30 p.m.	12.6		7 p. m.	28.5
June 23	7 a. m.	10.4	July 13	7.30 a.m.	27.5
	8 p. m.	8		7.30 p.m.	27
June 24	7 a. m.	7	July 14	7.30 a.m.	26.4
	6 p. m.	5		7 p. m.	25.8
June 25	7 a. m.	10	July 15	8 a. m.	25.3
	7 p. m.	19.8		7 p. m.	24.8
June 26	11 a. m.	22.7	July 16	7 a. m.	24
	7 p. m.	23.4		8 p. m.	21.9
June 27	7 a. m.	24.6	July 17	8 a. m.	14
	7.30 p.m.	27.3		7 p. m.	10
June 28	7 a. m.	25	July 18	6 a. m.	9
	7 p. m.	24.3		7 p. m.	5
June 29	8 a. m.	23.5			



A. FLOOD IN NEOSHO RIVER AT HIGHWAY BRIDGE AT HUMBOLDT, KANS.

B. OVERFLOW OF RIGHT BANK OF NEOSHO RIVER AT HIGHWAY BRIDGE AT HUMBOLDT, KANS.

It is seen from these gage records that this river was in flood much of the time from April 24 to July 17. A stage of 27.3 feet above low water was reached April 25; a stage of 29 feet was reached June 4; a stage of 27.3 feet was reached on June 27; and a stage of 30.7 feet, the maximum for the year, was reached on July 10. The highest known water at this place prior to 1904 was in 1885. The flood of June 10, 1904, was about 1 foot higher in stage than at that time. The highest water of 1903 was about 3 feet less than the July flood of 1904.

The left bank of the river at Humboldt is comparatively high, so that the city did not suffer from the flood; the right bank, however, is low and was overflowed for a distance of about 3 miles back from the stream. Pl. VII shows views of the Neosho River during the flood. From it a good idea can be obtained of the extent of the overflow and also of the velocity of the water.

FLOODS NEAR NEOSHO RAPIDS, KANS.

A flood-gaging station was established at the Santa Fe Railway bridge at Neosho Rapids in April, 1904, at a point a short distance below the mouth of Cottonwood River. The fluctuations of the surface at this station, measured with a chain gage, are as follows:

Gage height, in feet, of Neosho River at Neosho Rapids, Kans., May 16 to July 18, 1904.

Date.	7.20 a. m.	6 p. m.	Date.	7.20 a. m.	6 p. m.
	Feet.	*Feet.*		*Feet.*	*Feet.*
May 16	20.6	21	June 4	[a] 35.2	34.3
May 17	26.2	27.2	June 5	33.4	33
May 18	27.8	24.3	June 6	31	29.5
May 19	21.9	19	June 7	28.1	27
May 20	14.7	14	June 8	26.1	24
May 21	13.8	13.6	June 9	18.7	18
May 22	13.6	13.5	June 10	16.2	22.6
May 23	13.4	13.4	June 11	28.3	30.4
May 24	13.3	13.3	June 12	29.7	28.4
May 25	12.9	12.9	June 13	25	23.5
May 26	14	14.9	June 14	18	16.5
May 27	21.1	21	June 15	15.5	15
May 28	19.4	19	June 16	17	19.1
May 29	20	30	June 17	20.5	21.5
May 30	32	34.1	June 18	23	23.7
May 31	33.6	32	June 19	25.2	26.5
June 1	31.9	30.9	June 20	26.5	24.2
June 2	28.5	28.6	June 21	20.2	17.2
June 3	31.8	33.2	June 22	16	15.8

[a] 6 a. m.

Gage height, in feet, of Neosho River at Neosho Rapids, Kans., May 16 to July 18, 1904—Continued.

Date.	7.30 a.m.	6 p.m.	Date.	7.30 a.m.	6 p.m.
	Feet.	*Feet.*		*Feet.*	*Feet.*
June 23	15	14.5	July 6	31.4	[illegible]
June 24	14	14	July 7	34.4	[a]36.1
June 25	22.7	25	July 8	35.2	35.1
June 26	31.1	32.2	July 9	34.4	[illegible]
June 27	33.3	32.8	July 10	33.8	[illegible]
June 28	31.2	29.6	July 11	33.2	33
June 29	27.1	26.6	July 12	32.8	32
June 30	25.3	24.5	July 13	30	29.4
July 1	22.3	20.1	July 14	27.1	23
July 2	17.1	16.6	July 15	17.5	16.1
July 3	18.6	18.5	July 16	16.9	17
July 4	19.1	20.4	July 17	16.5	16
July 5	24.2	26	July 18	15.2	14.4

[a] Midnight.

It is seen from these figures that there have been five floods of considerable magnitude at this place from May 17 to July 14, 1904. The first one reached its maximum on May 18, with a gage height of 27.8 feet; the second reached its maximum on May 30, with a gage height of 34.1 feet; the third reached its maximum June 4, with a gage height of 35.2 feet; the fourth reached its maximum June 27, with a gage height of 33.3 feet, and the fifth reached its maximum July 7, with a gage height of 36.1 feet. The highest flood of 1903 at this place reached an elevation of about 2½ feet less than the stage on July 7, 1904.

FLOOD NEAR EMPORIA, KANS.

Cottonwood River rises in the eastern part of McPherson County and flows in a general eastwardly direction, emptying into the Neosho about 8 miles southeast of Emporia. The distance from source to mouth in a straight line is about 75 miles. The river falls from an elevation of about 1,475 feet to 1,045 feet. The extreme width of the watershed is about 40 miles. The land is hilly, or gently rolling, prairie, pasture, or cultivated land, without many trees, except along the streams.

There is no gage at Emporia on either the Cottonwood or Neosho, but the records relative to high floods are kept at the Emporia pumping station on the Neosho and at J. R. Soden's mill, near Emporia, on the Cottonwood.

The highest water at Soden's mill prior to 1904 was on May 28,

1903. On June 3, 1904, the water was 28 inches higher at this mill than on May 28, 1903, and on July 5 and 6, 1904, the water was 22 inches higher than on May 28, 1903.

According to the record of Mr. F. A. Bacon, engineer of the Emporia Waterworks Company, the highest water at the pumping station prior to 1904 was on May 29, 1903, at which time the water was 35½ inches deep on the floor of the engine room. On May 29, 1904, the water was 29½ inches deep on its floor. On June 3, 1904, it again was 29½ inches deep. On June 26 it was 28 inches deep, and on July 6, 1904, at 12 noon, it was 36½ inches deep. The water remained from July 5 to 8 in the pump house—that is, for three days the stage of the river remained within 3 feet of the greatest height it ever attained. Nearly all the country between these two rivers in the vicinity of Emporia was flooded and the crops destroyed. The railroads along the river and crossing it were tied up for several days. The Neosho branch of the Missouri, Kansas and Texas Railroad, which extends from Junction City to Parsons, suffered severely, but none of the bridges were washed away.

FLOOD NEAR CHANUTE, KANS.

About 3½ miles north of Chanute the Neosho makes a sharp bend to the west side of the valley, and remains on that side for about 7 miles. The major part of the water of the 1904 flood, instead of following this large bend, cut across it at a velocity sufficiently large to badly damage the levees in its path, destroy the crops, and cause considerable loss to the oil interests. Several of the oil tanks were moved from their foundation, some of them were overturned, and a few were swept away. The pumping machinery was injured to some extent by the dirty water.

The flood of July passed at least 1 foot in depth over all the levees. Nearly all of them were damaged to some extent and in places they were completely destroyed. The greatest damage was usually around culverts that passed the water through the levee. The water was so high here that a boat was rowed through the doors of a freight car standing on the Missouri, Kansas and Texas Railroad near the depot. The flood marks at the pumping station indicate that the July, 1904, flood was about 8 inches higher at Chanute than the flood of 1885 and was about 2 feet higher than the highest water of 1903.

FLOOD NEAR FORT GIBSON, IND. T.

A gaging station was established on Neosho River at the Missouri Pacific Railway bridge near Fort Gibson, Ind. T., in September, 1903, and the following gage heights were taken during June and July, 1904, during the floods on the upper river.

Gage height, in feet, on Neosho River near Fort Gibson, Ind. T., 1904.

Date.	May.	June.	July.	Date.	May.	June.	July.
1		14.00	18.80	17		17.00	25.00
2		18.60	18.20	18		16.50	24.00
3		20.00	20.00	19		17.00	23.00
4		26.50	21.00	20		17.50	21.00
5		33.00	22.60	21		18.20	19.20
6		32.60	23.00	22		18.00	19.00
7		29.00	26.00	23		17.10	18.20
8		27.00	27.00	24		16.40	16.00
9		27.00	28.00	25		15.00	15.80
10		25.50	29.00	26		15.40	15.20
11		25.50	32.40	27		16.00	14.80
12		24.00	32.20	28		18.80	14.40
13		24.00	32.00	29	11.80	19.00	13.80
14		22.20	31.60	30	12.00	19.80	14.00
15		20.00	30.80	31	13.00		
16		19.50	30.00				

It is seen from this table that the river was high during June and July. A maximum stage of 33 feet was reached on June 5 and again a maximum stage of 32.4 feet on July 11, this last being about 23 feet above low water.

LEVEES OF NEOSHO COUNTY.

Levee building was begun in Neosho County, Kans., in 1892, and has gradually grown until at the present time there are 19 levee districts along Neosho River, varying in size from 220 acres to 2,000 acres, depending upon the topography of the country. A stream or high land that does not need the levee serves as a boundary. The height of the levees is referred to the height of the greatest flood of 1885, the crown of each levee being supposed to be from 1½ to 2 feet above the flood height of that year. The crown width varies from 3 to 6 feet, the latter being the width of those recently completed.

The side slopes vary from 1½ to 1 to 2 to 1, the greatest height being about 10 feet. The material for the levees is obtained near the place of construction, and is usually very good for the purpose, as it contains a considerable amount of clay. The cost of construction ranges from 7 to 18 cents per cubic yard, and the cost per acre reclaimed from $8 to $12. The Nixon levee, for instance, built in 1903, protects 626.1 acres and cost $5,681.90. The cost per year for repairs varies widely, depending on exposure to action of river, ranging from

thing to $1.25 per acre, but generally amounting to from 25 to 50 ıts an acre. Some levees built nine years ago have required no ɔairs. These levees have protected the land against ordinary flood, d as most of the land thus protected is almost valueless without od protection they have well repaid the cost of their construction. ıe belief is very general that several of them are too near the river, d thus restrict the stream waterways, and that they are not suffi- ntly high and thick. The levee districts are formed and the levees ilt and maintained by a board of county commissioners.

NECESSARY WIDTH OF CHANNEL.

For 230 miles from the mouth of the river its average slope is less ın 2 feet per mile, and there are long stretches where the slope is ly 1.7 feet per mile. The stream is also very crooked, so that the ective slope is smaller than that of other similar streams. The equent overflows of the river are due to the sluggish flow which sults from this small slope of bed. The only means of increasing e slope is by shortening the stream—that is, removing some of the nds. As this remedy is not practicable, the only remaining palli- ve is to make the waterway area large and use levees. As the lume of flood flow, the average slope of the stream, and the depth water are known, it is possible to compute the approximate size of trapezoidal channel that will safely carry the flood flow without erflow of levees of a reasonable height.

The flood discharge of the Neosho at Iola in 1904 was about 75,000 bic feet per second, and the depth of water was about 23 feet above v water. The average surface slope at this place is approximately ; feet per mile. The effective slope is somewhat less, and we will sume it to be 2.2 feet per mile. The coefficient of roughness of bed) in Kutter's formula is assumed to be 0.030. From these data we d that a trapezoidal channel having a bottom width of 420 feet, le slopes 1.5 to 1 or top width of 486 feet, depth 22 feet, will carry volume of 75,000 cubic feet per second.

That is, if the channel of the Neosho in the vicinity of Iola were proximately trapezoidal in shape with a top width of 486 feet, ttom width 420 feet, and banks or levees on each side, so that the erflow could not take place for a height of water of 22 feet above v water, the flood of 1904 would have passed down the stream with- t overflow. The width between the abutments of the bridge at la is only 190 feet, so that there was a very large overflow on each le of the bridge.

In the vicinity of Chanute and farther down the river, where the pe of the stream is considerably less than at Iola, the top width of e channel will need to be from 650 to 700 feet between the levees.

DAMAGE DONE BY FLOOD.

The damage done along this stream consisted mainly in the loss of crops. The overflow water had very little velocity, but spread out over a large area, ruining a large acreage of crops, but not destroying the land, as was the case along Kansas River during the 1903 flood. The cities and towns along the river are, as a rule, situated a considerable distance back from the river and out of the reach of floods. Very few bridges were injured by the flood. The railroads suffered quite heavily, especially the Missouri, Kansas and Texas, which parallels the river. For several days trains could not run over this road, and the loss in traffic and injury to roadbed was large. The oil industries along the river, especially in the vicinity of Chanute, suffered heavily in loss of time and damage to machinery. The levees along the river in Neosho County, described on page 92, suffered to a large extent.

PREVENTION OF FUTURE DAMAGE.

Floods occur annually on the Neosho that cause overflow of much valuable land, destroying crops and making agriculture very uncertain. This overflow is due to the small slope of the river, small area of waterway, and to the numerous bends in the stream.

Levees have been used to prevent overflow in some parts of the river valley and serve their purpose well in the case of ordinary floods. By building levees sufficiently far apart to give a larger waterway to the river, building them a few feet higher, and protecting them at exposed places they will protect the land against all floods.

VERDIGRIS RIVER FLOODS.

Floods are common on Verdigris River. Rarely a year passes without a flood that causes overflow of some of the bottom lands along the river. There were five floods on this river from April 26 to July 10, 1904, that reached a stage of more than 27 feet above low water at Independence, and two of these reached a stage of more than 41 feet above low water.

STREAMS AND DRAINAGE BASIN.

Verdigris River rises in the southeastern corner of Chase County, Kans., flows in a southerly direction through Kansas and part of Indian Territory, and empties into Arkansas River. Its length, as found by measurement on the best available maps, is 290 miles. It

falls from an elevation of 1,400 feet at its source to 700 feet at a point about 11 miles north of the Kansas and Indian Territory line, a distance of 141 miles. From this point to the mouth, a distance of 148 miles, it falls about 100 feet. Throughout its length the river flows in a well-defined channel with banks from 10 to 40 feet in height. The width at ordinary stage of water at the State line is 140 feet and at the mouth 250 feet. It is essentially a surface run-off stream; its water is muddy, its flood flow large, summer flow small, and surface fluctuations quite large and rapid. Although it flows in a comparatively deep and well-defined channel, its banks are frequently subject to overflow during floods, on account of the sluggish flow due to small fall and crooked channel. The bed and banks are composed of firm material, that changes very little from year to year.

The principal tributaries of Verdigris River are Fall River, Elk River, Caney River, and Bird Creek. These all enter the river from the west and take a southeasterly direction. The first three rise in the Flint Hills of Butler County, Kans., and the last in Indian Territory.

Caney River, the largest of the four, drains an area of 2,440 square miles, has a length of 140 miles, and falls from an elevation of 1,500 feet at its source to 750 feet near the State line, a distance of 48 miles.

Fall River is 96 miles long and has a fall of from 1,500 to 750 feet in a distance of 43 miles. Its drainage area is 875 square miles. Its water is less muddy and its flow more steady than that of Verdigris River. The width near the mouth at ordinary low water is 75 feet.

Elk River drains an area of 687 square miles. Its length is 70 miles and its width near the mouth at ordinary low water 75 feet. It falls from an elevation of 1,500 feet to 750 feet in a distance of 43 miles. Its discharge is smaller and its flow less steady than Fall River, resembling the main stream in this respect.

Bird Creek has a length of 85 miles and drains an area of 1,340 square miles.

The watershed of Verdigris River has an area of 8,610 square miles. Its total length is 180 miles and its greatest width 72 miles. The Flint Hills, in the northern part of its boundary, have an elevation of about 1,600 feet. The northern boundary varies in height from 1,200 to 1,400 feet. The eastern boundary falls from about 1,400 to 650 feet and the western boundary from 1,600 to 650 feet, decreasing from the north toward the south. The upper part is comparatively rough, the general fall toward the river being about 25 feet to the mile. This portion of the watershed is used for grazing purposes. The rest of the basin contains some of the best farming land in the Mississippi River Valley. In some parts the general surface is

broken by mounds having an elevation of from 100 to 250 feet above the general level; such is Table Mound, 6 miles northwest of Independence, and the mounds near Fredonia and Cherryvale, Kans., and near Sageeyah, Ind. T.

The following table gives the distance in miles between 50-foot contours along Verdigris, Fall, and Elk rivers:

Distance, in miles, between 50-foot contours along Verdigris, Fall, and Elk rivers.

Elevation in feet.	Distance between contours.		
	Verdigris River.	Fall River.	Elk River.
1,300 to 1,250	3	2	1
1,250 to 1,200	2	2	2
1,200 to 1,150	7	3	2
1,150 to 1,100	4	3	4
1,100 to 1,050	3	3	3
1,050 to 1,000	7	6	3
1,000 to 950	6	13	4
950 to 900	12	22	4
900 to 850	30	19	6
850 to 800	32	16	16
800 to 750	8	.....	12
750 to 700	26	.....	.....
700 to 600	148	.....	.....

DISCHARGE AND RUN-OFF.

A gaging station was established on the Verdigris August 2, 1895, at McTaggart's mill, 7 miles east of Independence and 3 miles southwest of Liberty. The gage consists of two parts, one a vertical timber spiked to the flume of the mill and reading from 0 up to 8 feet, the other of foot and half-foot marks painted on the wheelhouse of the mill. Discharge measurements have been made from the highway bridge a few hundred feet below the dam.

The channel at this place is straight for several hundred feet above and below the bridge. The flow has a moderate velocity at low as well as high stages. The bed is mainly rock and not subject to change. The banks, although of considerable height, are subject to overflow during very high floods.

The following table shows the mean monthly and annual discharge and run-off obtained at this station from 1896 to 1903:

ated monthly discharge of Verdigris River at Liberty, Kans., 1895–1903.

[Drainage area, 3,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
st	7,121	20	783	48,144	0.294	0.255
mber	37,000	87	5,985	356,132	2.179	1.953
ber	155	39	69	4,248	.025	.022
mber	171	39	82	4,879	.030	.027
nber	28,000	68	4,226	259,847	1.589	1.378
1896.						
ary	1,136	450	661	40,643	.249	.216
uary	770	256	426	24,503	.145	.139
h	351	171	242	14,880	.091	.079
	3,882	171	677	40,285	.246	.221
	19,900	171	4,181	257,080	1.572	1.363
	16,620	303	2,200	130,909	.800	.717
	10,770	138	1,699	104,467	.639	.554
st	210	14	46	2,828	.017	.015
mber	424	5	71	4,225	.026	.023
ber	8,720	9	600	36,893	.226	.196
mber	9,130	110	1,017	60,516	.369	.331
nber	1,010	171	448	27,547	.168	.146
The year	19,900	5	1,022	744,776	4.548	.333
1897.						
ary	1,616	351	887	54,540	.333	.289
uary	5,276	450	1,591	88,360	.532	.518
h	14,470	553	2,201	135,333	.838	.718
	26,100	450	2,829	168,338	1.030	.923
	8,105	256	1,260	77,474	.474	.411
	4,005	52	505	30,050	.184	.165
	4,989	39	408	25,088	.153	.133
st	39	20	28	1,722	.011	.009
mber	20	20	20	1,190	.008	.007
ber	20	5	8	492	.003	.003
mber	5	2	2	119	.001	.001
nber	39	2	12	738	.004	.004
The year	26,100	2	813	583,444	3.571	.267

Estimated monthly discharge of Verdigris River, etc.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1898.						
January	1,010	9	[a] 106	[a] 6,518	[a] 0.04	[a] 0.03
February	10,606	39	[a] 1,084	[a] 60,202	[a] .37	[a] .35
March	6,383	52	1,335	82,086	.51	.44
April	3,267	230	859	51,114	.31	.28
May	30,690	579	6,185	380,303	2.33	2.02
June	10,073	475	2,455	146,082	.89	.80
July	5,727	39	390	23,980	.15	.13
August	7,285	9	498	30,620	.18	.16
September	4,087	2	515	30,645	.19	.17
October	256	14	61	3,751	.02	.02
November	830	28	121	7,200	.04	.04
December	10,942	87	1,457	89,588	.54	.48
The year	30,690	2	1,255	912,089	5.57	.41
1899.						
January	660	210	319	19,615	.120	.104
February	2,652	68	342	18,994	.116	.112
March	3,062	303	997	61,303	.374	.325
April	6,424	400	1,244	74,023	.453	.406
May	9,253	256	1,631	100,286	.613	.532
June	21,440	190	3,893	231,650	1.410	1.269
July	29,876	154	4,433	272,574	1.663	1.445
August	1,800	20	234	14,388	.087	.076
September	20	5	16	952	.006	.005
October	20	2	7	430	.002	.002
November	14	9	12	714	.004	.004
December	28	14	18	1,107	.007	.006
The year	29,876	2	1,096	796,036	4.855	.357

[a] Approximate.

Estimated monthly discharge of Verdigris River, etc.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1900.						
January	90	55	65	3,997	.020	.020
February	240	40	82	4,554	.030	.030
March	10,200	170	1,323	81,348	.500	.430
April	10,750	140	1,236	73,547	.450	.400
May	16,500	280	2,455	150,952	.920	.800
June	5,400	110	593	35,286	.210	.190
July	23,610	222	1,824	112,153	.680	.590
August	155	7	53	3,259	.020	.020
September	36,950	10	3,714	220,998	1.350	1.210
October	35,075	280	3,236	198,974	1.220	1.060
November	25,430	860	3,766	224,093	1.370	1.230
December	860	368	531	32,650	.200	.170
The year	36,950	7	1,573	1,141,811	6.970	.510
1901.						
January	860	280	465	28,592	.174	.151
February	2,200	368	920	51,094	.312	.300
March	7,458	368	1,006	61,857	.379	.328
April	16,260	760	3,272	194,697	1.195	1.067
May	2,550	90	554	34,064	.209	.181
June	810	40	122	7,259	.045	.040
July	90	3	13	799	.005	.004
August	205	2	30	1,845	.012	.010
September	2,200	2	153	9,104	.056	.050
October	90	40	55	3,382	.021	.018
November	40	27	37	2,202	.013	.012
December	55	40	51	3,136	.020	.017
The year	16,260	2	556	398,031	2.441	.182

Estimated monthly discharge of Verdigris River, etc.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1902.						
January	55	40	45	2,767	0.01	0.01
February	1,780	40	204	11,330	.07	.07
March	785	140	357	21,951	.14	.12
April	810	187	268	15,947	.10	.09
May	26,438	205	5,395	331,718	2.03	1.79
June	33,018	960	7,893	469,666	2.87	2.57
July	4,525	320	1,050	64,562	.39	.34
August	6,577	100	1,051	64,623	.39	.34
September	15,650	368	2,935	174,645	1.07	.96
October	11,080	464	1,706	104,898	.65	.56
November	8,470	464	1,598	95,088	.58	.52
December	6,433	685	1,852	113,875	.69	.60
The year	33,018	40	2,030	1,471,070	8.99	.66
1903.						
January	1,060	610	747	45,931	.28	.24
February	21,020	392	2,348	130,401	.79	.76
March	17,800	1,164	4,112	252,837	1.54	1.34
April	19,900	910	3,031	180,357	1.10	.99
May	41,450	910	10,865	668,063	4.08	3.54
June	26,480	560	3,981	236,886	1.45	1.30
July	7,458	464	1,551	95,367	.59	.51
August	4,000	560	1,514	93,092	.56	.49
September	8,810	280	1,306	77,712	.48	.43
October	3,407	464	1,100	67,636	.42	.36
November	11,150	660	2,367	140,846	.87	.77
December	-------	-------	-------	-------	.69	-------
The year	-------	-------	-------	-------	1.285	-------

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 266; rating table in Paper No. 39, page 450.

Gage heights and discharge measurements for 1900 are given in Water-Supply Paper No. 50, page 331; rating table in Paper No. 52, page 518.

Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

It is seen that the minimum flow at this place is sometimes only 2 second-feet for sixty or more days at a time. The maximum daily rate of discharge during this period was 41,450 second-feet, on May 23, 1903.

The following table gives the maximum and minimum rate of discharge and run-off at this station:

Maximum and minimum discharge of Verdigris River at Liberty, Kans.

[Drainage area, 3,067 square miles.]

Year.	Date.	Gage height in feet.	Maximum discharge in second-feet.		Date.	Gage height in feet.	Minimum discharge in second-feet.	
			From total drainage area.	Per square mile.			From total drainage area.	Per square mile.
1895	Sept. 11	[a] 35.50	[b] 37,000	12.1	October	2.20	155	0.051
1896	May 24	23.75	19,900	6.49	September	1.70	5	.0016
1897	Apr. 30	[c] 28.00	26,100	8.51	November and December.	1.60	2	.00065
1898	May 4	[d] 31.00	30,690	10.0	September	1.60	2	.00065
1899	July 9	30.45	29,876	9.74	October	1.60	2	.00065
1900	Sept. 30	36.00	[b] 36,950	12.0	August	1.55	7	.0023
1901	Apr. 13	20.40	16,260	5.30	August and September.	1.20	2	.00065
1902	June 7	33.37	33,018	10.8	January and February.	1.90	40	.013
1903	May 23	39.00	[b] 41,450	13.5	September	2.80	280	.091
1904	July 8	41.00	50,400	16.43				

[a] Absolute maximum, 36.40.
[b] Probably too small on account of overflow of banks.
[c] Absolute maximum, 28.20.
[d] Absolute maximum, 31.50.

FLOODS NEAR INDEPENDENCE.

A flood-gaging station was established on Verdigris River at the highway bridge at Independence in April, 1904. The fluctuations of the surface measured with this gage are given on page 102.

Gage height of Verdigris River at Independence, Kans., April to July, 1904.

Date.	Time.	Height.[a]	Date.	Time.	Height.[a]
		Feet.			*Feet.*
April 24	6.15 p.m.	19	June 18	5.30 a.m.	32.5
April 25	6.12 a.m.	25.4		7.30 p.m.	36.6
	10.50 p.m.	28.1	June 19	5.30 a.m.	37.4
April 26	6 a. m.	30.1		6.30 p.m.	35.7
	5 p. m.	31.5	June 20	6 a. m.	33.5
May 7	6 a. m.	15		6 p. m.	29.1
	1 p. m.	16.1	June 21	6 a. m.	22.6
June 2	6 a. m.	13		6 p. m.	16.6
	6 p. m.	16.8	June 22	6 a. m.	14.4
June 3	6.35 a.m.	29.1	June 26	9 a. m.	18.2
	5 p. m.	35.8	June 27	7 a. m.	23.4
June 4	6.30 a.m.	36.6		7 p. m.	25.5
	8 a. m.	37	June 28	5 a. m.	26.9
	9.45 a.m.	37.4		7 p. m.	25.1
	11.12 a.m.	37.8	June 29	6 a. m.	23
	12 m	38.0		7 p. m.	19.4
	1 p. m.	38.3	June 30	6 a. m.	15.8
	3 p. m.	38.7	July 1	5.30 a.m.	17.4
	4 p. m.	39		6.30 p.m.	21
	5.37 p.m.	39.3	July 2	5 a. m.	24.6
	7.35 p.m.	39.7	July 4	5 a. m.	31.9
	11 p. m.	40.1		6 p. m.	26.5
June 5	6 a. m.	40.7	July 6	7.30 a.m.	29.1
	9 a. m.	41.5		1 p. m.	33.9
	3.30 p.m.	40.8	July 7	7 a. m.	36.2
	5.30 p.m.	40.9		8 p. m.	39.2
	7.25 p.m.	41.5	July 8	7.30 a.m.	41.6
June 12	5.30 a.m.	30.9		6 p. m.	43.2
	5 p. m.	31.2	July 9	5 a. m.	42.8
June 13	6 a. m.	30.7	July 10	5 a. m.	39.8
	6 p. m.	29.8		6 p. m.	38
June 14	5.30 a.m.	23.3	July 11	6 a. m.	36.1
	7 p. m.	11.5		6 p. m.	34.1
June 15	5.30 a.m.	12	July 12	6 a. m.	31.4
	7.30 p.m.	12		7 a. m.	26.3
June 16	6 a. m.	19.6	July 13	6.30 a.m.	20.5
	7.30 p.m.	27.7		6 p. m.	13.5
June 17	5.30 a.m.	28.7	July 14	5 a. m.	8
	7 p. m.	29.6	July 15	5 a. m.	4.9

[a] Above low water.

It is seen that the river was at a high stage at Independence from April 24 to July 13. It reached a maximum of 31.5 feet on April 26, a second maximum of 41.5 feet on June 5, a third maximum of 37.4 feet on June 19, a fourth maximum of 31.9 feet on July 4, and a fifth maximum of 43.2 feet above low water—the largest of the year—on July 8. There was a range of stage at this place of about 43 feet, as compared with a range of 22 feet on the Neosho at Iola and 36 feet on Fall River at Fall River. It is seen further that the changes of stage, though larger, are not as rapid on the Neosho as on Fall River, where a change in stage of 6 feet in two hours was observed during the July flood of 1904.

Mr. F. N. Gorden, pump engineer of the Independence waterworks, has high-water marks of the floods of 1885, 1895, 1903, and 1904 on the pump house, from which the comparative heights of these floods have been obtained and the gage height at the station near Liberty on July 8 was computed. The elevations of the high-water marks above low water were as follows: July 8, 1904, 43.2 feet; June 5, 1904, 41 feet; 1903, 41 feet; 1895, 38 feet; 1885, 37.7 feet.

The Verdigris makes a U-shaped bend in passing Independence. The major part of the flood water cut across this bend and greatly retarded the flow in the channel proper during the flood. Mr. F. N. Gorden describes the river at the pump house as being nearly as still as a lake during the highest water, while before the water cut across the bend it was flowing with quite rapid velocity. This reduction of velocity in the main channel after overflow begins makes it very difficult to compute the flood discharge of the stream. The water begins to overflow the bottom land opposite Independence at a height of about 35 feet above low water, or 8 feet below the high water of July, 1904. The width of the flooded portion in the vicinity of Independence was about 3 miles. Wheat is the chief crop grown in this river bottom in this vicinity, and the part of the wheat that had been cut prior to these floods was piled up against the hedges and resembled in some places small straw stacks. From the flood heights, as shown by the gage heights and high-water marks at Independence and the flood heights and rating curve of the gaging station at Liberty, the flood discharge of the Verdigris at Liberty on July 8, 1904, has been computed. The overflow portion of the flood is estimated to have been 12,500 cubic feet per second and the total discharge 50,400 cubic feet per second.

FLOOD ON THE LOWER VERDIGRIS.

A considerable amount of damage was done by the floods in the vicinity of Coffeyville. A portion of the city was flooded, in addition to the loss of crops in the bottoms. The high water decreased from the Kansas and Indian Territory line to the mouth of the stream.

FLOOD IN LOWER FALL RIVER VALLEY.

The fluctuations of the surface of Fall River during the floods of 1904 can be seen from the following gage readings, taken at the gaging station at Fallriver, from which the flashy character of this stream is easily seen:

Gage height of Fall River at Fallriver, Kans., 1904.

Date.	7 a.m.	5 p.m.	Date.	7 a.m.	5 p.m.
	Feet.	*Feet.*		*Feet.*	*Feet.*
April 22	3.5	3.5	June 20	8	7.1
April 23	.....	4	June 21	9.2	6.4
April 24	26.3	29.5	June 22	6	5.4
April 25	14.5	12.5	June 23	9	5.2
April 26	9.3	7.3	June 24	5	4.8
April 27	6.5	6.1	June 25	10	18.5
April 28	6.1	6	June 26	11.2	8
April 29	5.9	5.8	June 27	18.5	9
April 30	5.7	5.7	June 28	8	7.2
May 31	7	6.4	June 29	7.5	18
June 1	8	18.3	June 30	19	9.5
June 2	9.5	10.5	July 1	7.5	16.2
June 3	24	27.5	July 2	20	24.5
June 4	33.5	25.4	July 3	12.5	8
June 5	12.5	10.3	July 4	8	16.4
June 6	8.4	7.5	July 5	9	21.5
June 7	6.8	6	July 6	32.5	33.6
June 8	5.5	5.5	July 7	30	31.5
June 9	13.5	8.8	July 8	31	15.1
June 10	23.5	34.8	July 9	10.4	10
June 11	31	20.7	July 10	9	18.4
June 12	10	8.5	July 11	14	9
June 13	8	7.4	July 12	7.5	7
June 14	13.2	8.5	July 13	6.5	6.2
June 15	9	7.8	July 14	6	6
June 16	37.8	35.6	July 15	5	15.4
June 17	27.5	17	July 16	8	6.5
June 18	10.4	7.5	July 17	5	4.8
June 19	8.2	16			

It is seen that this stream reached a maximum stage on April 24 of 29.5 feet, reached a second maximum on June 4 of 33.5 feet, a third maximum on June 10 of 34.8 feet, a fourth maximum on June 16 of 37.8 feet, and a fifth maximum on July 6 of 33.6 feet, in addition to

smaller maximum stages between the larger ones. On the evening of April 23 the gage read 4 feet; the next morning it read 26.3 feet—a rise of 24.3 feet in ten hours. On the evening of June 15 the gage read 7.8 feet; the next morning it read 37.8 feet—a rise of 30 feet in ten hours. There were six floods of this stream from April 23 to July 8 in which the gage read from 22 feet and four when it read above 35 feet.

This flashy character of Fall River is due to the steep, impervious nature of the watershed.

These floods caused little overflow above the station, but at Fredonia and Neodesha an area of from 2 to 5 miles in depth was submerged by the four highest floods, and the crops on the submerged land were destroyed. Less stock was lost in these floods than in any recent flood of equal magnitude, because of the warnings telephoned and telegraphed from the station to the property owners down the valley.

There are high-water marks at the Frisco Railroad pumping station near the gage—one of 1898 and one of 1869. The flood of June 3, gage height 35.5 at 3 a. m., came to the mark of 1898, and the flood of June 10, gage height 36.8 feet at 9 p. m., came above that of 1869. The flood of June 16 was from 3 to 4 feet higher than any previous known flood.

NECESSARY WIDTH OF CHANNEL OF VERDIGRIS RIVER.

The average slope of Verdigris River for 150 miles from the mouth is less than 2 feet per mile, and there are long stretches where it is not more than 1 foot per mile. This is a very small slope for a small stream. The frequent overflows are due almost entirely to the small slope and consequent sluggish flow. The only practical remedy for overflow is the construction of levees on each side of the river where overflow takes place, at such a distance apart that there will be ample room for the passage of floods between them.

If the flood volume, the height of floods above low water, and the slope of the stream are known, it is possible to compute the area of waterway to pass the maximum flow without overflow.

The flood of 1904 had a maximum rate of discharge at Independence of 50,400 cubic feet per second and the height of the flood above low water was about 40 feet. With these data and the assumption that the slope is 1.5 feet per mile and the coefficient of roughness of bed 0.030, we find that a channel of trapezoidal cross section having a bottom width of 105 feet and a top width of 225 feet will carry a volume of 50,500 cubic feet per second, and the mean velocity of flow will be about 7.6 feet per second. The channel cross section at the gaging station on the highway bridge near Liberty has a bottom width

of about 150 and a top width of about 275 feet, so that if the slope of the river were 1.5 feet per mile during floods, this channel would carry the water without the stage reaching the height of 40 feet above low water; but, unfortunately, the slope decreases as the stage increases. The mean velocity should be 7.2 feet, but it probably was less than 5 feet per second.

DAMAGE DONE BY FLOOD.

The damage done by the flood along this river consisted mainly of loss of crops, due to overflow of the bottom land. Part of the wheat crop was in shock at the time of the first high flood, and this was carried off the fields and piled up against the fences. That part of the wheat crop that was standing was injured to such an extent that little of it was harvested; in fact, the crops on all the area flooded were destroyed. Little damage was done to the ground itself, as the velocity was not sufficient to cause scour. There was little loss of stock, owing mainly to the very efficient way in which the high water was predicted from the flood stations.

OSAGE RIVER FLOODS.

STREAM AND DRAINAGE BASIN.

Osage River rises in the northeastern part of Wallace County, Kans., flows in a general easterly direction, and empties into Missouri River near Osage City, Mo. The distance from the source to the mouth in a straight line is about 210 miles, but the length of the river is at least 400 miles, as it is very crooked for a considerable part of its course. It falls from an elevation of about 1,225 feet to 755 feet, near Ottawa, in a distance of about 50 miles, but for a distance of about 25 miles on either side of Ottawa the fall is not more than 1½ feet per mile. From Ottawa to the mouth of the river there is a fall of about 330 feet in 434 miles. The stream flows in a fairly deep channel, that changes little from year to year, as the soil contains a considerable amount of clay; but it overflows frequently, due to very heavy rainfall and sluggish flow.

The watershed above the gaging station at Ottawa has an area of 1,237 square miles, its greatest length being about 55 miles and its greatest width 27 miles. It is hilly or gently rolling, and consists of pasture and cultivated lands, with little tree growth except along the streams.

GAGE HEIGHT AND DISCHARGE.

A gaging station was established at Main Street Bridge, Ottawa, August 26, 1902. The channel is nearly straight for about 100 feet

above and 75 feet below the station, and has a width between abutments of about 138 feet, without piers. The bed is rock and gravel and is permanent. The flow is moderately rapid. Although the channel is deep, both banks are subject to overflow during floods. Fluctuations of the surface are measured with a chain gage fastened to the bridge. The mean daily gage height and corresponding discharge obtained at this station from readings each morning and evening during the floods of 1904 are given below:

Gage height and discharge of Osage River at Ottawa, Kans., May, June, and July, 1904.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec. feet.*		*Feet.*	*Sec. feet.*
May 15	3.10	1,450	June 8	3.25	1,630
May 16	20.35	[a] 22,140	June 24	2.65	920
May 17	24.25	26,820	June 25	16.45	17,460
May 18	23.05	25,380	June 26	22.90	25,200
May 19	9.15	8,700	June 27	26.25	29,220
May 20	3.40	1,810	June 28	25.00	27,720
May 21	3.10	1,450	June 29	10.40	10,200
May 25	2.40	650	June 30	8.30	7,680
May 26	7.00	6,120	July 1	8.30	7,680
May 27	9.40	9,000	July 2	5.85	3,550
May 28	4.90	3,610	July 3	6.10	5,040
May 29	([b])		July 4	7.35	6,540
May 30	31.80	35,880	July 5	4.95	3,670
May 31	[c] 30.00	33,720	July 6	19.60	21,240
June 1	28.00	31,560	July 7	25.55	28,380
June 2	26.40	29,400	July 8	30.15	33,900
June 3	24.60	27,240	July 9	29.50	33,120
June 4	24.75	27,420	July 10	27.25	30,420
June 5	24.45	27,060	July 11	17.45	18,660
June 6	17.00	18,120	July 12	4.65	3,310
June 7	5.95	4,860			

[a] Discharges for stages above 20 feet are very doubtful and are probably too small.
[b] Record lost, owing to high water.
[c] Gage heights from May 31 to June 2 obtained by interpolation.

It is seen that there were three floods at this place from June 30 to July 10—one that reached a mean daily stage of 31.8 feet and discharge of 35,880 second-feet on May 20; a second that reached a mean daily stage of 26¼ feet and discharge of 29,220 second-feet on June 27; and a third that reached a mean daily stage of 30.2 feet and discharge of 33,900 second-feet on July 8. The maximum stage reached for a short time on May 10 was 34.3 feet.

The flashy character of this stream can easily be seen from the rapid fluctuation in stage and discharge.

The greatest flood on this stream prior to 1904, in the recollection of the oldest inhabitants living along it, was in May, 1898, the highest stage reached at Ottawa being about 29 feet. The first flood of 1904—that of May 30—reached a stage at Ottawa of 34.3 feet, that is, about 5 feet higher than the 1898 flood. The second flood of 1904—that of June 27—reached a stage at Ottawa of 26.6 feet, that is, to within 2½ feet of the flood of 1898. The third flood of 1904—that of July 8—reached a stage of 30.7 feet, that is, 2 feet higher than the flood of 1898.

Each of these floods was due to very heavy rainfall following a period of excessive precipitation. The rainfall for May, 1904, was 11.68 inches, and the rainfall in the twenty-four hours just preceding the flood was 5.20 inches. In May, 1898, when the previous great flood occurred, the rainfall for May was 11.67 inches, and the rainfall for the twenty-four hours just preceding the flood was 4.06 inches.

DAMAGE DONE BY FLOODS.

The 1904 floods on this river appear to have been higher and did more damage in the vicinity of Ottawa than anywhere else along the stream. The damage done was due mainly to the water overflowing and standing on the ground, and very little to scouring action. About 250 houses in Ottawa were flooded and their occupants driven out. The city water, gas, and electric-light plants were flooded and the city left without water and light for several days. The water stood 1½ feet in depth on the floor of the Santa Fe Railway station, and about 3 inches in depth on the floor of the Missouri Pacific Railway station. Railway traffic was suspended for about three days. The river bottom was flooded for several days for a width varying from one-fourth mile to 2 miles, and all the crops in the overflowed portion were destroyed. Some stock in the river bottoms was destroyed; also numerous fruit trees, especially the smaller ones. The water passed over the three bridges in Ottawa, but none of them was injured to any great extent. The water was 3 feet in depth on Main Street Bridge, where the gage is located.

The second flood, which reached its height about June 27 at a gage height of 26.6 feet—that is, 7.7 feet lower than that of May 30—was commented on by the Ottawa Republic as follows:

> While the area covered in Ottawa by this flood is considerable, not so many families have been compelled to move as ordinarily have in the case of floods of equal height, for the reason that the big flood caused a score or more of lowly homes to be washed away that never have been replaced.

During the third flood, which reached its height July 8 at a gage height of 30.7 feet, the city's supplies of water and gas were again cut

off. Many persons were driven from their homes. Business and railway traffic were nearly suspended for a few days.

PREVENTION OF FUTURE DAMAGE.

The area of waterway at Main Street Bridge, Ottawa, is about 4,000 square feet to the lower surface of the bridge. The overflow area here was probably at least 6,000 square feet. The actual area provided for passing the discharge of this stream is, therefore, not more than 40 per cent of the water area on May 30, 1904. The Atchison, Topeka and Santa Fe Railway crosses the river on an embankment. The water overflowed this road and wore holes several cubic yards in capacity in some places, showing that there was a considerable difference in elevation of the water on the upstream and downstream sides of the embankment and that the embankment acted as a dam. Large trees grow close to the water's edge along this stream. These trees, while they served to protect the banks from erosion, retarded the flow, and drift collected in front of them, forming a dam. Conclusive evidence of this action can be seen a short distance above the upper bridge in Ottawa. This is a crooked stream, with rather sluggish flow, and if the flood height is to be reduced to a minimum the flow should not be obstructed by bridges, embankments, trees, and the like.

ARKANSAS RIVER FLOODS,

GAGE HEIGHT AND DISCHARGE.

The floods on Arkansas River from Wichita to Arkansas City were greater in 1904 than ever known before. Maximum fluctuations of the river surface from May 30, 1889, to July, 1904, given by the United States Weather Bureau gaging station on Douglass Avenue Bridge, at Wichita, are given below:

Maximum stages of Arkansas River at Wichita, Kans.

Date.	Gage height.	Date.	Gage height.
	Feet.		*Feet.*
May 3, 1889	5.3	April 13, 1901	6.0
June 10, 1889	5.6	June 9, 1901	4.3
June 10, 1899	6.3	June 3, 1902	5.9
April 22, 1900	7.0	June 2, 1903	7.6
May 28, 1900	7.4	June 4, 1904	6.0
June 8, 1900	7.2	July 9, 1904	10.2

It is seen that the July 9, 1904, flood was 2.6 feet higher than any previous flood since the gaging station was established, but this differ-

ence in gage height between the floods of 1904 and other floods does not convey an adequate idea of the difference in volume. The recorded range of stage of the Arkansas at Wichita is only about 10.5 feet, whereas the range of stage of the Neosho at Iola is 22 feet, that of Fall River at Fallriver is 36 feet, and that of the Verdigris at Independence is 43 feet. Yet the change in volume of the Arkansas is from 70 to 40,000 second-feet, whereas the change in volume of the Verdigris is only from 30 to 50,400. Arkansas River flows in a relatively wide, shallow channel, with low banks and sandy, changeable bed, with a considerable fall and rapid velocity, making it impossible for the change of stage to be as great as that of the Verdigris or the Neosho, on account of the shallow channel and steep slope.

FLOOD NEAR ARKANSAS CITY.

The fluctuations of the surface of the Arkansas at Arkansas City during the floods of 1904 and the corresponding discharge are given by the gage readings below, taken at the United States Geological Survey gaging station in Arkansas City:

Gage height and discharge of Arkansas River flood at Arkansas City, June 1 to 8 and July 1 to 18, 1904.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec. feet.*		*Feet.*	*Sec. feet.*
June 1	6.20	3,200	July 6	10.50	13,955
June 2	8.10	7,125	July 7	13.30	27,347
June 3	11.20	14,440	July 8	14.20	33,503
June 4	12.90	21,470	July 9	14.90	38,291
June 5	13.30	24,100	July 10	15.20	40,355
June 6	10.80	13,290	July 11	14.50	35,555
June 7	8.90	8,810	July 12	13.80	30,767
June 8	8.10	7,125	July 13	12.50	21,875
July 1	7.00	4,355	July 14	11.80	17,855
July 2	6.60	3,555	July 15	9.20	10,055
July 3	7.50	5,445	July 16	8.10	6,915
July 4	8.70	8,565	July 17	7.20	4,775
July 5	9.50	10,955	July 18	7.00	4,355

It is seen that two floods occurred here this season—one that reached its maximum on June 5, with a gage height of 13.3 feet, and another that reached its height on July 10, with a gage height of 15.2 feet and a discharge of 40,355 second-feet. The ordinary gage reading of low water at Arkansas City is about 2 feet, so that these flood crests are 11.3 and 13.2 feet, respectively, above low water. There is

a difference of only about 2 feet in the elevation of the crests of these floods at Arkansas City, whereas the difference in elevation of the crests at Wichita is about 4 feet. This is partly due to the flood of the Little Arkansas at Wichita, and to the greater facility for spreading out over the valley at Arkansas City. Both banks at the latter place are low and subject to overflow. A levee of sand banks on the right side prevented overflow of that bank, but the left bank was submerged for half a mile from the river. The maximum depth of this overflow on July 10 was about 5 feet. The area of overflow was 7,205 square feet, and the total flood area 11,287 square feet. The total discharge was 40,335 cubic feet per second. The flood of July remained for five days higher than ordinary floods, and being about 2 feet higher destroyed a much larger area of the river bottom than ever before. A pile bridge across the river at Arkansas City was swept away by the flood.

FLOOD NEAR WICHITA.

The fluctuations of the surface of Arkansas River at Wichita and Hutchinson, furnished by Mr. George T. Todd, United States weather forecaster, are as follows:

Gage height of Arkansas River at Wichita and Hutchinson, Kans., July 2 to 18, 1904.

[United States Weather Bureau record.]

Date.	Wichita.	Hutchinson.	Date.	Wichita.	Hutchinson.
	Feet.	*Feet.*		*Feet.*	*Feet.*
July 2	3.2	3.4	July 11	8.6	2.8
July 3	4.6	3.2	July 12	7.6	2.7
July 4	4.3	3.4	July 13	6.3	2.7
July 5	5.5	3.9	July 14	4.8	2.6
July 6	7.1	4.9	July 15	3.9	2.6
July 7	9.1	4.7	July 16	2.8	2.6
July 8	10.1	4.2	July 17	2.3	2.5
July 9	10.2	3.8	July 18	1.9	2.5
July 10	9.7	3.0			

NOTE.—Crest of 1904 flood was about 2 feet higher than that of 1903 and a little higher than crest of 1879 flood.

The low-water gage reading at Wichita is —0.6 foot, so that the excess of the July flood was about 10.8 feet above lowest low water.

Flood marks here indicate that the flood of 1877 did not reach as great an elevation as the flood of July 8, 1904. About three-tenths of the city of Wichita was submerged during the larger of the two

floods. Indeed, it appeared on the night of July 8 that about nine-tenths of the city was under water, but the greater part of this water came from a very heavy rain, and not from streams.

The larger part of the overflow came from Little Arkansas River and Chisholm Creek. This creek traverses a considerable portion of the city, but its waterway there was not sufficiently large to carry the flood safely, and the area on each side was flooded. The Little Arkansas is very crooked and empties into the Arkansas where the channel is very narrow. As a result of this, the water backed up and submerged a considerable portion of the city in that vicinity. There are seven bridges across the Arkansas within the city limits of Wichita, and each of them, with the single exception of the Douglas Avenue Bridge, rests on piles, which collected the drift, retarded the flood, and caused overflow.

The damage in the city due to the overflow is estimated to be about $30,000. All the railway tracks in the vicinity were under water and traffic greatly delayed or suspended. The farmers, however, living along the river valley suffered to the greatest extent, as all the crops on the submerged land were destroyed.

The gage readings at Hutchinson, given above, show that the flood was very small at this place.

FLOOD ON WALNUT RIVER.

Walnut River rises in the southern part of Marion County, flows south and empties into Arkansas River near Arkansas City. Its length from source to mouth in a straight line is about 75 miles. It falls from an elevation of about 1,410 feet to 1,030 feet at its mouth. Its watershed joins that of the Cottonwood on the north, of the Verdigris on the east, and of the Arkansas on the west. Its greatest width is about 35 miles, and its area is about 946 square miles. It consists of gently rolling pasture or cultivated land, with little timber except along the river banks.

The rainfall and floods of this river in 1904 were greater than ever known before. There is a gage on the downstream side of one of the piers of the Frisco Railroad bridge in Winfield, also high-water marks on this bridge and the machinery room of a mill near by, from which the following data in regard to the floods of 1904 and previous floods have been obtained.

Four great floods have occurred here in the recollection of the inhabitants—those of 1877, 1898, June 4, 1904, and July 8, 1904.

The high-water mark of 1898 was surpassed by 25½ inches in the flood of July 8, 1904, and by 14½ inches in that of June 4, 1904. The marks of the 1877 flood are not very distinct, but the general belief is that the flood of July 8, 1904, was somewhat higher than that of 1877,

as the highway bridge at Winfield was built above the high-water mark of that flood, and the water in July, 1904, was 8 inches in depth on the floor of this bridge.

PENNSYLVANIA FLOODS.

By E. C. MURPHY.

Floods of short duration, due to heavy downpour of rain, have occurred at a number of places on comparatively small streams with steep, narrow channels, during the past year. Two of these, namely, Robinson Run and Johnstown, both in Pennsylvania, will be described in this paper. They illustrate the need of providing an ample way for such streams and of keeping it always open. Sooner or later the damage caused by such floods will much more than offset the small gain due to encroachments on the natural width of the stream.

JOHNSTOWN FLOOD.

Damage amounting to several thousand dollars was done at Johnstown, Pa., by a very heavy downpour of rain on Saturday evening, July 8, 1904. During the twenty-four hours ending at 8 a. m. July 9, 2.98 inches of rain was measured at the United States Weather Bureau station, of which 1.45 inches fell between 8 and 9.30 p. m. on the 8th. This rain fell so very rapidly that the street gutters could not carry off the water with sufficient rapidity, and the streets were flooded, sewers clogged, and basements and cellars of houses entered. The hills surrounding Johnstown are very steep; the minor streams, one-half mile to 2 miles in length, that are ordinarily dry became very much swollen and, passing down the steep hillsides, carried large amounts of gravel and bowlders that quickly choked culverts and other waterways, causing overflow into the streets and surrounding territory.

The flood down Bedford street is thus described in the Johnstown Tribune:

> The occasion of all the damage on Bedford street was the little stream—ordinarily the merest rivulet—which drains Meyers Hollow. The cloud-burst of Saturday night converted this brooklet into a raging flood which tore down Brown avenue to Bedford street, bearing with it tons of earth, rocks, and logs. Its first onslaught was on the house of D. B. Parker, the lower floor of which was almost instantly covered to a depth of 3 feet with slimy mud. From here the flood swept on down Bedford street to the corner of Main, where it formed a veritable lake. As usual, the cellars of the Merchants' Hotel, Nathan's, and Swank Hardware Company were attacked, and with the exception of Swank's, where an electrical pump kept ahead of the influx, were pretty well filled.

The quantity of material brought down by these streams delayed the street cars for several hours. Traffic on the Pennsylvania Rail-

road was delayed for ten hours by the landslide at Buttermilk Falls, all four of the tracks being covered to a depth of several feet.

The rainfall which caused this damage, though large, was local, as shown by the flow of the larger streams. The readings of the United States Weather Bureau gage at Franklin Street Bridge, Johnstown, on Stony Creek, show very little change of stage.

Gage height at Johnstown, Pa., 1904.

Date.	Height in feet.	Date.	Height in feet.
July 8	3.6	July 11	3.6
July 9	3.5	July 12	3.0
July 10	5.4	July 13	2.8

It is easily seen that this damage was not due to overflow of the principal streams, but to that of the minor streams, and to the fact that the street gutters in the low part of the city were not large enough to carry off the water that fell on the streets.

ROBINSON RUN FLOOD.[a]

On June 28, 1904, there occurred a flood on Robinson Run that did much damage to property along its banks, especially in Oakdale, Pa.

This stream is a comparatively small one that rises about 20 miles west of Pittsburg, Pa., flows in a southeasterly direction, and empties into Ohio River about 2 miles west of Pittsburg. Its principal tributary is Robb Run, which enters it near Oakdale. The watershed has steep, uncultivated slopes, with little timber. The stream has a steep slope and a rapid run-off. The Pennsylvania Railroad runs along Robinson Run from Walkers to Oakdale, thence along Robb Run to beyond McDonnell.

The flood occurred on the evening of June 28. During the day there were occasional heavy showers, and from 6 to 7 in the evening it rained very heavily, especially along the north branch of Robinson Run. As a result these two streams, especially Robinson Run, were transformed into raging torrents.

Some damage was done at McDonnell on Robb Run. This creek rose to flood stage in about fifteen minutes and was back again to near its normal stage in about two hours. It overflowed its banks, filling cellars with water, damaging furniture, and carrying away sidewalks and a few small bridges.

The flood on Robinson Run was much larger than on Robb Run.

[a] From report in Oakdale Times.

Its height at Oakdale was due, in part at least, to the obstruction of the channels in and just below the town, where it was badly obstructed by the railway bridge. The water was about 15 feet deep in the creeks at Oakdale and 7 feet deep on the floor of the Oakdale Times office. All the buildings in the lower part of the town along the creek were flooded. Sixty families lost their furniture and 11 houses were either destroyed or very badly injured. Some of the business houses lost a considerable amount of stock, damaged by the water. Three bridges across Robinson Run in the vicinity of Oakdale were destroyed, also other bridges farther down the creek. The total loss was estimated to be about $30,000, one-half of which was for bridges.

TROXTON CANYON FLOOD, ARIZONA.[a]

By E. C. Murphy.

Floods of great magnitude and destructiveness occurred in western Arizona on the headwaters of the Big Sandy, a tributary of the Williams, and on Sacramento Wash, a small tributary of Colorado River, in the latter part of July and August, 1904.

The gorge commonly known as Troxton Canyon is about 3.5 miles long and is located about 40 miles northeast of Kingman, Ariz. The country is mainly a barren, treeless, elevated plateau with an occasional low range of mountains, through one of which, known as Cottonwood Cliffs, the Big Sandy has cut its way, forming the gorge in question. This is crooked and its bed has a very steep slope. The Santa Fe Railway passes through it, crossing it at several points on steel bridges.

The stream in this canyon is usually dry, but on July 30 it had a depth at one of these bridges of more than 30 feet and a very high velocity. The stream remained at maximum stage about half an hour.

The nearest place to the canyon where precipitation is measured is Kingman, Ariz. The records there show a rainfall in July of 0.79 inch. The precipitation over the greater part of western Arizona in August varied from 2 to 9 inches in depth, being 6 inches or more above the normal at some places. Unfortunately, so far as known, no measurements of stage or discharge of the floods were made along either of these streams in July or August.

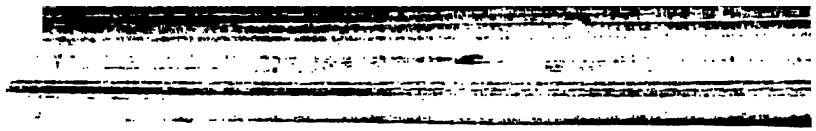
Five steel bridges of approved construction, built since 1898, cross the stream in the canyon. Two of these, of 80 feet span, were destroyed by the flood; two others of 80 feet span were not destroyed, but the water and drift passed over them; the fifth, consisting of

[a] Largely prepared from an article in the Railway Age by A. F. Robinson, bridge engineer of the Atchison, Topeka and Santa Fe Railway, on the damage to the railway property during the flood.

FIG. 10.—Erosion of bank of Big Sandy Creek and relocation of Santa Fe Railway, Troxton Canyon, Arizona. From Railway Age.

VIEW SHOWING EFFECT OF FLOOD ON ABUTMENTS AND BRIDGE NO. 604, SANTA FE RAILWAY, TROXTON CANYON.

From Railway Age.



three 80-foot spans, had about 60 feet of the east approach washed out. Bridge No. 604, an 80-foot bridge, was destroyed by this flood (Pl. VIII). Although the east abutment of this bridge weighed over 600 tons, it was carried by the water about 150 feet downstream and turned through an angle of about 180 degrees. The west abutment was founded on rock, the east one on adobe, resting on a concrete footing extending 7 or 8 feet below the bed of the stream on a timber grillage. There was a protection wall at right angles to

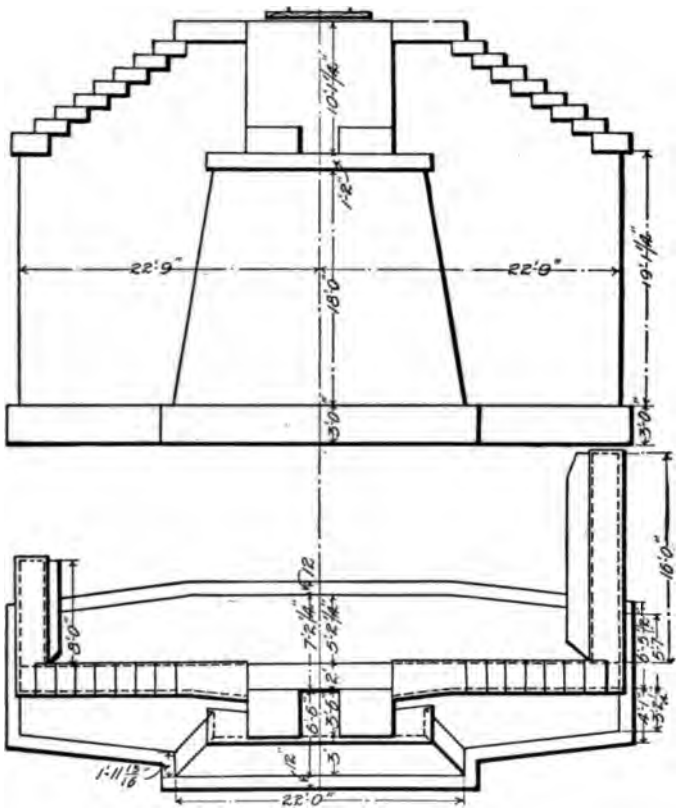


FIG. 11.—Design of east abutment of bridge No. 604, Santa Fe Railway, Troxton Canyon, Arizona. From Railway Age.

the abutment and extending about 16 feet into the bank to prevent the water from cutting around the end, but the stream cut under this and tipped it and carried away the abutment. The protection wall was not carried down to the depth of the main part of the abutment; possibly if it had been the abutment might not have failed. The water not only destroyed this east abutment, but washed away the bank to a distance of about 35 feet. Fig. 11 shows a plan and an elevation of this east abutment; fig. 10 shows erosion of channel in the vicinity of bridge No. 604 and relocation of railway.

During August there were almost daily floods on this stream and other streams in western Arizona, making the railroad repairs very difficult and expensive. On August 2 one of the largest of these floods occurred, doing considerable damage in this canyon and also along Sacramento Wash, through which the Santa Fe Railway passes. Between Yucca and Haviland the bridge and 600 feet of road were destroyed.

The damage caused by the flood was almost entirely to the railway line, and comprised a large loss of business, traffic being suspended fifteen days. From Los Angeles to Albuquerque for some days it was necessary for the Santa Fe trains to pass over the Southern Pacific tracks to Maricopa and thence north through Phoenix to the Santa Fe tracks.

From slopes and cross sections in this canyon taken after this flood by the Santa Fe engineers it has been estimated that the maximum in this canyon was approximately 49,000 second-feet.

GLOBE FLOOD, ARIZONA.

By O. T. Reedy.

The Pinal Creek flood of 1904, generally known as the Globe flood, since both the rainfall which caused it and the greatest damage occurred in the immediate vicinity of Globe, Ariz., took place on the afternoon of August 17. The rain began to fall about 5.30 p. m. in a gentle shower, which in a few minutes increased to a veritable cloud-burst, continuing without abatement for about three-quarters of an hour. Pinal Creek began to rise within fifteen or twenty minutes after the rain commenced, and reached its highest point about 6 o'clock. The storm was local, extending from the divide 5 or 6 miles to the southwest and southeast of Globe to about the northern limits of the town. The area covered was only about 25 or 30 square miles. The water all fell within an hour, and measured 2.05 inches at Globe. In order to estimate the amount of the flood waters I took several cross sections of the creek up to the high-water mark, and also measured the slope of the creek bed. From these data, and assuming n, the coefficient of roughness, to be 0.025, the discharge per second was computed by Kutter's formula. The first cross section was taken just behind Mr. A. Kinney's barn, the high-water mark being a point shown by Mr. Kinney. The discharge at this point as computed is about 11,000 feet per second, which is checked pretty closely by the computed discharge for a cross section taken 200 or 300 yards below, at the footbridge. The discharge at the latter point was about 11,500 second-feet. Between this point and the northern limit of the rainfall two large drainages, Graveyard

Wash and Copper Hill Wash, flow into Pinal Creek. No measurements were taken on the former, because it added very little to the flood water, and all the high-water marks were made a couple of weeks after the big flood, at a time when the wash was discharging four or five times as much as at the time of the flood. Copper Hill Wash was measured and the discharge found to be about 3,000 second-feet. This, added to the last above-mentioned discharge of the creek, makes 14,500 second-feet, which checks pretty well with the computed discharge at the third cross section. This was taken at a point about a hundred yards above the Government warehouse, and at about the limit of the rainfall. The above discharge data are given in the tabulation below:

Data on discharge of Pinal Creek and Copper Hill Wash, Globe, Ariz., August 17, 1904.

Locality.	Area, cross section.	Wetted perimeter.	Hydraulic radius.	*n*.	Slope.	Coefficient, C.	Discharge.
	Sq. feet.	*Feet.*					*Sec. feet.*
Pinal Creek:							
Kinney's barn	800	200	4.0	0.025	0.008	76	10,900
Footbridge, Broad st.	610	90	6.8	.025	.008	82	11,500
Copper Hill Wash:							
About ¼ mile from mouth	105	28	3.8	.025	.042	76	3,200
United States warehouse	963	240	4.0	.025	.008	76	13,200

The average duration of the high waters of the flood, as given by a number of observers, was about forty to fifty minutes. Estimating that the discharge was half the maximum for an hour longer and one-fourth the maximum for two hours more, the total quantity of water discharged is as follows:

	Cubic feet.
45 minutes, at 14,000 cubic feet per second	37,800,000
60 minutes, at 7,000 cubic feet per second	25,200,000
120 minutes, at 3,500 cubic feet per second	25,200,000
Total	88,200,000

If this amount of water were distributed evenly over 25 square miles the depth would be 1.52 inches. This, of course, does not necessarily disagree with the 2 inches observed rainfall at Globe, since the area covered by the rain is more or less estimated, and it is reasonable to suppose that over part of this area the fall was much less.

Cross sections were also measured about 15 miles below Globe, at

Wheatfields, where the computed discharge averaged about 5,000 second-feet. I was unable to determine how long the flow continued. Mr. Devore, who lives at Wheatfields, stated that the water began to come down about 8 o'clock and that the water was nearly normal next morning. Estimating the average flow at one-half the computed discharge, and its continuance at eight hours, gives 72,000,000 cubic feet as the total quantity of water. This does not greatly disagree with the Globe observations.

The principal damage caused by the flood was to the property of the Gila Valley, Globe and Northern Railway. The stock yards and a number of cottages occupied by the railway employees were partly washed away. All the bridges and culverts in the lower part of town were either destroyed or badly damaged and long stretches of the roadbed entirely carried away. The loss was about $5,000. The balance of the damage was sustained principally by the merchants on lower Broad street. Several buildings were lifted from their foundations and carried across the street. The goods in these buildings were all destroyed. In many other buildings the water stood 18 inches deep, destroying or damaging much of the contents. The total losses, including that of the railroad, were about $18,000.

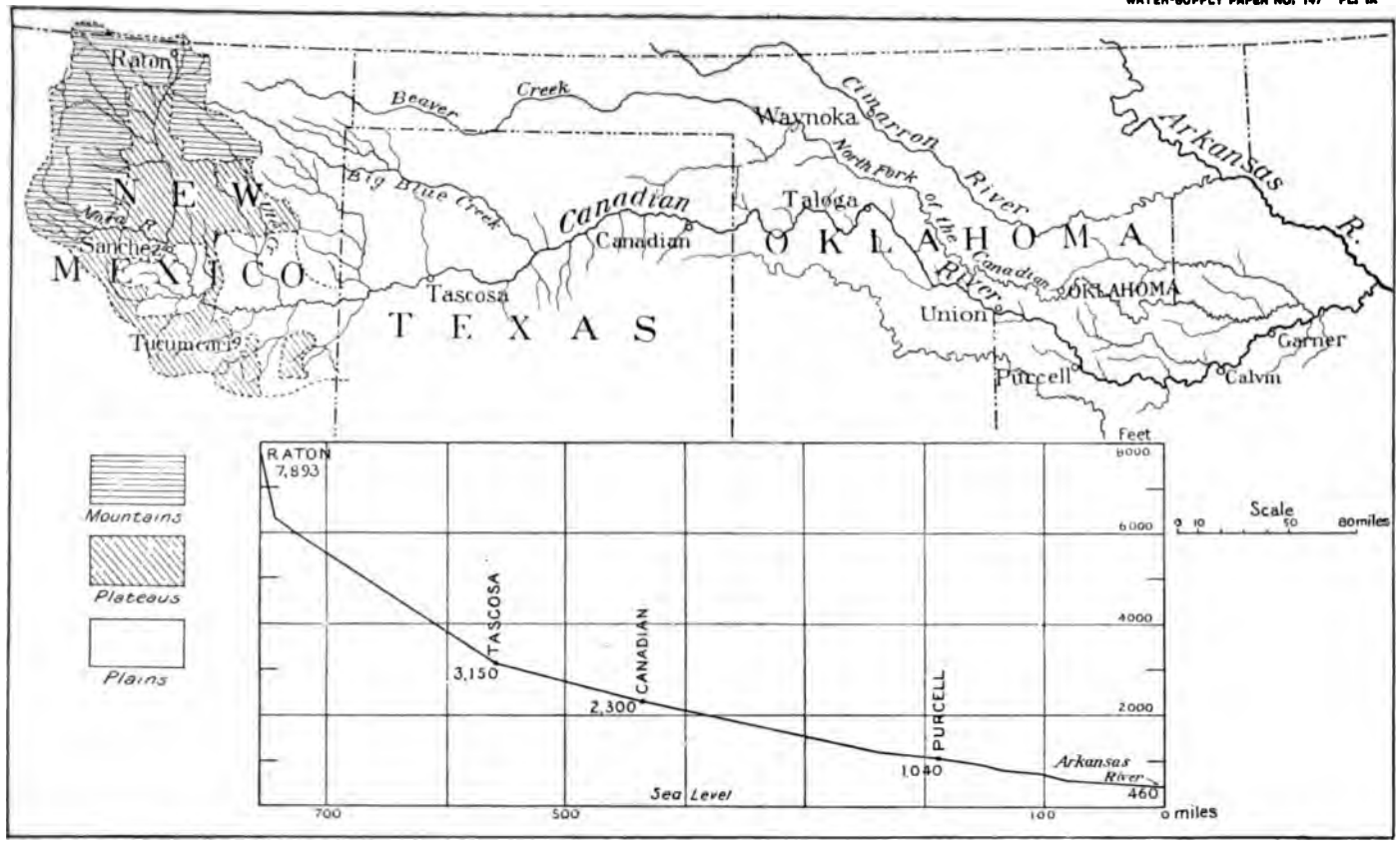
A most distressing feature of the flood was the great loss of life. Six persons were drowned in a few minutes. The first one was probably asleep in his cabin on the low ground when the wall of water came down and carried the building away. The other five persons were in the Mitchell boarding house. When the flood set in there were eight persons in the house, two of whom made their escape, and a third, son of the proprietor, went to secure ropes with which to rescue the others, three of whom were women, one a cripple. Before he could return the house and its occupants had been swept away.

I am indebted to Mr. Jos. H. Hamill, of the Silver Belt; Mr. A. Kinney; Mr. Cottee, of Cottee & James, electricians, and Mr. M. S. McEniry, of the United States Geological Survey, for the greater part of the information upon which this report is based.

CANADIAN RIVER BASIN FLOOD, NEW MEXICO, OKLAHOMA, AND INDIAN TERRITORY.[a]

From September 30 to October 2, 1904, occurred the largest and most destructive flood on record in the upper part of the Canadian River drainage basin. It was caused by a very heavy downpour of rain September 28 to 30 on the headwaters of this river. Although much damage was done along the stream in Oklahoma and Indian Territory the storm causing the flood did not extend beyond the eastern border of New Mexico, as Ute Creek, which drains a narrow

[a] Prepared mainly from report of Frank S. Dobson and George B. Monk, engineering aids.



DRAINAGE BASIN AND PROFILE OF CANADIAN RIVER.

ip extending nearly north and south in the eastern part of New exico, did not show any marked rise during the period.

STREAMS AND DRAINAGE BASIN.

The Canadian River basin comprises a long, narrow strip of land ng between the Arkansas and Red River drainage, extending rthwest from the east boundary of Indian Territory through Okla-

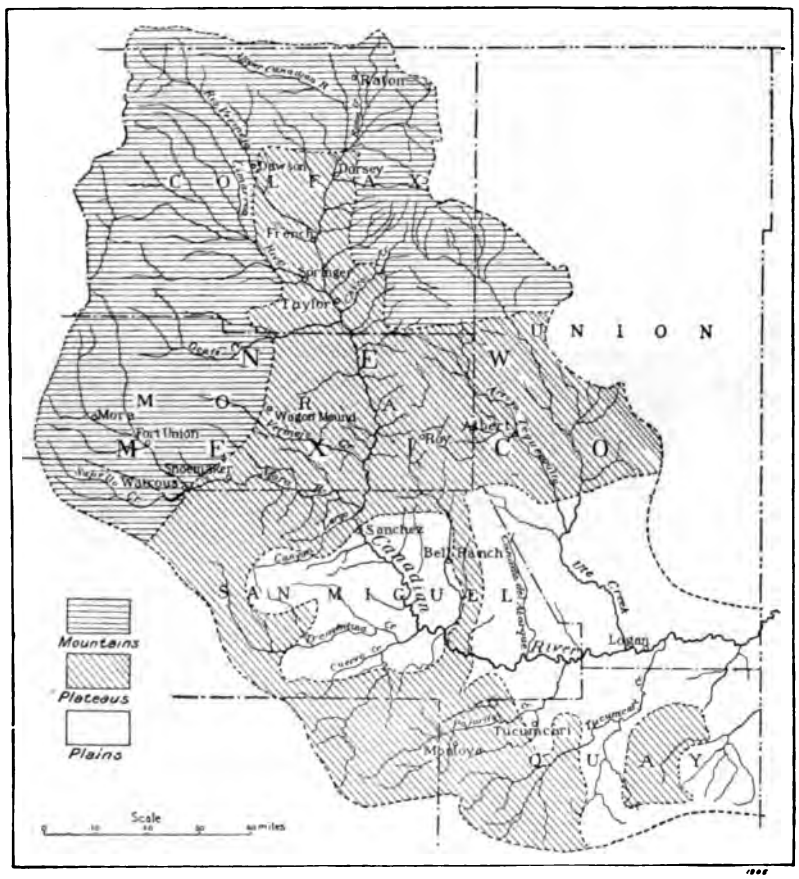


FIG. 12.—Upper portion of drainage basin of Canadian River.

ma, Indian Territory, and northern Texas to the northern part of ew Mexico. Its total length is about 875 miles, its greatest width 0 miles. (See Pl. IX.)

The part of the basin in New Mexico where the flood occurred comises an area of about 12,600 square miles, 3,900 square miles of nich is classified as mountainous, 4,600 as plateau, and 4,000 as ains.

The mountainous part ranges in elevation from 8,000 to 12,000 feet, me of the peaks being covered with perpetual snow and having

little vegetation. The lower mountainous part is covered with wild grasses and some forest growth. The high plateaus are deeply cut by canyons of varying width, with numerous side canyons, from which the smaller streams emerge. These canyons become deeper and wider with the descent until the plains are reached. On these last are scattered high mesas.

The plains are covered with a fine sandy loam, which produces a thick growth of wild grass similar to that on the plateaus. The Canadian cuts through these plains in a canyon about 100 feet deep and from 600 to 800 feet in width.

The chief tributaries of the Canadian in New Mexico are Ute Creek, 96 miles long, with a drainage area of 2,010 square miles; Trementina Creek, 60 miles long, with a drainage area of 670 square miles; Pajarito Creek, 42 miles long, with a drainage area of 570 square miles; Ocate Creek, 72 miles long, with a drainage area of 560 square miles; and Cimarron River, 45 miles long, with a drainage area of 1,050 square miles. The following table shows the slope of the river:[a]

Profile of Canadian River, New Mexico.

Locality.	Distance from mouth in miles.	Height above sea in feet.	Fall per mile in feet.
Mouth	0	460	.....
	22	500	1.8
	82	600	1.7
	104	700	4.5
	134	800	3.3
	152	900	5.6
Near Purcell	190	1,040	3.7
Chicago, Rock Island and Pacific Railway crossing	240	1,200	3.2
Canadian	435	2,300	5.6
Tascosa	550	3,150	7.4
	727	5,972	15.9
	745	6,292	17.8
Raton Pass, head	758	7,893	123.2

The location of the above mentioned tributaries is shown in fig. 12, and the profile of the river in Pl. IX (p. 120). The only other tributary of the Canadian of importance is North Fork, which enters the main river about 35 miles from its mouth.

[a] Gannett, Henry, Profiles of rivers: Water-Sup. and Irr. Paper No. 44, U. S. Geol. Survey, 1901, p. 66.

Canadian and its tributaries have a steep slope and a rapid The floods usually occur in spring and are due to the melting They rise and fall slowly and remain at nearly maximum for several days. Occasionally, as in the instance under dis- ı, they are due to rain and are of short duration, rising and ; very rapidly. The great velocity of the river, however, these floods to be very destructive.

PRECIPITATION.

n September 26 to 30 the precipitation over the greater portion drainage basin of the Canadian in New Mexico varied from 5 nches, as shown by the following table, prepared from the l States Monthly Weather Review:

Precipitation in New Mexico, September 26–30, 1904.

'lace.	Greatest in 24 consecutive hours.	September—					Total.
		26.	27.	28.	29.	30.	
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
.....	2.24	0.10	.....	0.22	2.40	1.54	4.26
ıch.....	2.17	.....	.....	.....	2.17	1.87	4.04
.....	2.77	.....	0.50	.96	2.65	2.77	6.88
nion.....	2.30	1.80	.70	1.50	2.30	.....	6.30
.....	3.98	1.50	.80	1.10	3.88	.....	7.38
r.....	.....	.....	.50	.30	3.10	1.50	5.40
o.....	2.30	.05	.37	.63	2.30	1.60	4.95
ı.....	2.80	.....	.....	.....	.....	.....	.....
axwell	3.67	.....	.....	.....	.....	.....	.....

total precipitation and excess for the month of September, ıt places in this drainage basin is shown in the following table:

Precipitation in New Mexico, September, 1904.

Place.	Number years record.	Precipitation.	Excess.
		Inches.	*Inches.*
.....	13	6.00	4.48
ıch.....	5	4.04	2.75
.....	2	7.11	2.77
ıion.....	43	6.84	4.77
.....	10	7.38	6.49
ı.....	.....	8.81	.....
o.....	.....	5.39	.....
anch. near Maxwell	.....	7.65	.....

This excess of monthly rainfall varied from 2.75 to about 6.5 inches in depth; the greatest precipitation in twenty-four consecutive hours was about 4 inches. Such a downpour of rain on a basin of steep, nonabsorbent surface with little or no storage resulted in a sudden and very large, though local, flood.

FLOOD ON CANADIAN RIVER.

The gage at the gaging station at Logan was destroyed on October 2, 1904. The mean daily gage readings to the time when the gage was washed away are as follows:

Gage height, in feet, of Canadian River at Logan, N. Mex., September 26 to October 1, 1904.

September 26	0.80
September 27	2.35
September 28	4.25
September 29	7.50
September 30	25.00
October 1	30.00

This record shows a rise of over 29 feet above low water at Logan. How much higher the river rose after the gage was destroyed the observations do not show.

The cross sections of the flood plain and slope of the river bed were measured at places on the river and its principal tributaries, and the discharge computed by Kutter's formula: $Q=FC\sqrt{RS}$, using a coefficient of roughness $n=0.035$. The results are given in the following table:

Data of Canadian River basin flood, 1904.

Stream.	Place.	Discharge in second-feet.	Duration of high stage in hours.
Canadian	Logan	140,555	12
Do	Taylor	91,140	7
Do	French	156,000	.5
Mora	Watrous	76,000	.5
Sapello	Mouth	62,900	.5

Mr. W. G. Russell measured the cross section and slope of bed of the Canadian a short distance below the railway bridge at Logan on October 27, 1904, and found the cross-section area to be about 13,500 square feet, the mean velocity 11.05 feet, the maximum discharge 149,396 cubic feet per second, and the maximum stage above low water 31.3 feet.

Mr. D. P. Richards, a physician at Union City, Okla., states that on October 2, about 11.30 a. m., there was a sudden rise of about

4 feet in the Canadian. This was followed by a continued rapid rise until about 12.30 p. m. October 3, when the river reached its maximum stage. It remained nearly stationary for about nine hours and then began to subside. At 1 o'clock on the 4th it was again within its banks.

The following table gives the gage height on Canadian River at Calvin, Ind. T., Cimarron River at Waynoka, Okla., and Beaver Creek at Beaver, Okla., during the flood period:

Gage height, in feet, in Canadian River basin, September 29 to October 8, 1904.

Date.	Canadian River at Calvin, Ind. T.	Cimarron River at Waynoka, Okla.	Beaver Creek at Beaver, Okla.
September 29	.....	1	0.30
September 30	0.2	4.50	.30
October 1	.1	2.50	.70
October 2	.1	2	2.60
October 3	.0	2	3.15
October 4	9.0	2	2
October 5	4.2	4.50	1.70
October 6	2.0	3	1.30
October 7	1.2	1.50	1.15
October 8	1.0	2	.....

There are no available records of the flood of 1885, but old settlers say it was greater than any for many years prior to that date. An estimate of the discharge of the Canadian at Logan during it has been made by Mr. F. Dobson. From cross sections and slope of bed of stream, using Kutter's formula, the maximum discharge is placed at 70,000 cubic feet per second for about one hour. The estimated maximum discharge October 2, 1904, was 140,555 second-feet, or about double that of the flood of 1885.

FLOOD ON UTE CREEK.

The gage height at the gaging station on Ute Creek during the flood is given in the following table:

Gage height, in feet, on Ute Creek, September 26 to October 3, 1904.

September 26	0.20
September 27	.20
September 28	3.50
September 29	5.00
September 30	3.00
October 1	2.50
October 2	2.20
October 3	2.00

Although the watershed of this creek is part of the drainage basin of Canadian River, and is only a short distance from it, the flood on it was small, the rise being less than 5 feet above low water, while the rise at Logan on the Canadian was more than 30 feet. Neither North Fork of Canadian River nor Washita River, which flows parallel to the Canadian at Union and not a great distance from it, showed any signs of flood. The local character of the storm is evident.

FLOOD ON SAPELLO RIVER.

The gage at the gaging station on Sapello River, near Los Alamos, was washed out by the flood, and the bank to which it was attached was eroded to a distance of 40 feet back from the river. The river at this place rose above the top of the posts supporting the cable from which the discharge measurements were made.

The river began to rise early in the evening of September 29 and by midnight had reached the maximum stage. By 2 a. m. on September 30 it had receded about 2 feet. This stage was maintained for about forty-eight hours, when it gradually declined until October 7, at which time the discharge was about 150 second-feet. Heavy rains on October 8 again raised the river 2 feet, a height which was maintained for about twenty-four hours. From that time it decreased, and on October 12 the discharge was found by measurement to be 136 second-feet. The ordinary high-water width of the channel at the station is 115 feet, but the width at the highest stage was about 490 feet.

The maximum discharge at the gaging station was computed by Mr. Monk from Kutter's formula. The slope of the stream being 0.0004 foot per foot, the area 3,093 square feet, and the wetted perimeter 501 feet, and the coefficient of roughness being put at 0.040, the maximum rate of discharge was found to be 8,104 second-feet, and the total discharge from September 29 to October 10, inclusive, was found to be 67,370 acre-feet. As the drainage area above the gaging station is 221 square miles, this would mean a depth of about 5.71 inches over the entire area, and a run-off for the period from September 29 to October 10, inclusive, of 12.81 second-feet per square mile.

Several small irrigating dams about 7 miles above Los Alamos were washed out by the flood, but the volume of water liberated by their failure was not sufficiently large to produce any marked increase in the flood wave. Very little damage occurred in the immediate vicinity of Los Alamos, as the buildings and fields are high above the river and all crops were stacked above the high-water line.

Manuelitas River, which adjoins the Sapello at the town of Sapello,

was out of its banks from 8 p. m. on September 29 until noon of the following day. The town of Rociada, on the headwaters of this stream, was completely isolated for several days by the destruction of the road and telegraph wires.

FLOOD ON RIO MORA.

The gage at the highway bridge over Mora River at Weber was swept away by the flood, also the bridge itself, the observer's house, the post-office, and the store located near by. On September 29 the river began to rise early in the evening, reaching its maximum height of 12 feet about 10 p. m. By 7 a. m. on September 30 the water had fallen 6 feet. It then gradually dropped for five days to a stage such that the discharge was 200 second-feet. It was 3 feet higher on October 7 and 8 for about thirty hours, and then gradually declined until October 12, when a gaging gave a discharge of 196 second-feet. An estimate of the maximum discharge at this place was made by Mr. Monk, using Kutter's formula, and found to be 27,724 second-feet. The discharge for a stage 6 feet lower than the maximum was about 7,335 second-feet, and a stage 3 feet below the maximum gave a discharge of 18,927 second-feet. With these measurements of discharge and the fluctuations in stage, the total discharge from September 29 to October 10, inclusive, was found to be 173,249 acre-feet, the drainage area above the point of measurement being 422 square miles. This total volume corresponds to a depth of 7.69 inches over the drainage area and a run-off for the flood period of 17.25 second-feet per square mile. The damage done by the flood in the vicinity of Weber was estimated to be about $5,000.

Rio Cebolla and numerous small arroyos contributed a considerable amount of water to the river below Weber, the Cebolla alone discharging at maximum stage at the rate of about 600 cubic feet per second. Perhaps the worst devastation occurred at Watrous, the junction of Sapello and Mora rivers. Miles of the Santa Fe Railway tracks were washed out; houses, crops, fences, and bridges were swept away, and eight lives were lost in the town.

Excessive damage was caused by the flood in the entire Mora Valley. Commencing at the town of Mora, in the upper end of the valley, where the streets were submerged from 4 to 10 feet deep, about 30 houses were washed out and nearly 300 people rendered homeless. It is estimated that about half the crop in this vicinity was lost.

At La Cueva, 5 miles below Mora, the river was above the wagon bridge on September 27, and continued to rise until midnight of September 29, the maximum stage lasting about twelve hours. It remained out of its banks until October 5, when a decrease was appar-

ent until October 9, when the rains caused it to rise 2 feet. The channel during normal flow is about 32 feet wide, but the distance between the water lines during the flood was about 660 feet. A measurement of the discharge was made at this place by Mr. Monk, using Kutter's formula, and found to be 22,213 second-feet. The total discharge from September 29 to October 10, inclusive, was 161,849 acre-feet. The drainage area being 159 square miles, this volume corresponds to a depth of 9.305 inches over the whole drainage basin. The estimated run-off per square mile for the flood period of twelve days was 20.85 second-feet.

A large amount of damage was done in this vicinity, especially to crops and orchards belonging to the La Cueva Land and Cattle Company. About 500 yards above La Cueva the irrigating ditch, together with the country road to Mora, were washed out for a distance of 20 yards.

Turquillo Valley, a very productive section 8 miles north of the town of Mora, suffered greatly from the flood resulting from a four days' downpour. The waters from Canyon Carro and other minor arroyos originating in the adjacent hills swept through it, destroying the crops. In places the stream was over half a mile wide, and at one point near the upper end a lake of about 500 acres was formed, which will remain for some time, as it has no outlet.

OBSTRUCTION OF STREAMS.

The flood height at certain points was increased by structures across the streams. At French the Santa Fe Railway runs along the right bank of the river on a roadbed 12 feet above the river, while the El Paso and Northeastern Railway crosses it with approaches that restrict the stream to half its natural width. These obstructions, acting as a dam, backed the water over the Santa Fe tracks and depot, forming a lake one-fourth of a mile wide. At Springer the Santa Fe Railway crosses the Canadian on a bridge 170 feet wide between abutments and 17 feet above low water, the remainder of the channel being filled with the bridge approaches. Three miles below Watrous the Santa Fe Railway crosses Rio Mora at an angle, with long, high, filled approaches, the low-water channel only being bridged. At these three places the embankment caused backwater and finally gave way, after which the flood rapidly subsided.

DAMAGE DONE BY FLOOD.

It is impossible to give an accurate estimate of the damage done by this flood, and only a few of the larger losses will be mentioned.

Four miles of track and three bridges were destroyed on the Santa Fe Railway between Watrous and Shoemaker; the Rock Island Railway bridge at Logan, costing $60,000, was destroyed; the loss on the El Paso and Northeastern Railway from Taylor to French is estimated to have been $50,000; the loss of orchards, irrigation ditches, and 40 adobe houses at Sanchez, $50,000; in Mora River Canyon, between Watrous and Shoemaker, seven persons lost their lives, many houses were wrecked, and farms along the river damaged; the Rock Island Railway bridge at Lawton, consisting of two steel spans and two 60-foot steel-girder approaches, was destroyed, one span being carried downstream 3 miles, another 1 mile, and one of the steel girders, weighing 40 tons, 1½ miles; more than a mile of track was lifted and swept away; 700 feet of trestle approach to the Frisco Railroad bridge was completely destroyed; and similar damage was done at other places along the stream in Oklahoma.

The following information regarding the damage to railroads has been collected from railway officials of the various roads by Mr. Gerard H. Matthes, district engineer:

The Fort Worth and Denver Railroad lost about 600 feet of pile and trestle bridge across the Canadian near Tascosa, Tex., and had about 1,600 feet more damaged. Traffic was delayed four days. The approximate damage is estimated at $10,000.

The Atchison, Topeka and Santa Fe Railway sustained considerable damage at Purcell, Ind. T., where it has a roundhouse and extensive yards. The water during the flood stood from 2.5 to 3 feet deep in the yard and in front of the passenger depot and left a deposit of sand in some places 1 foot deep. Spur tracks were washed off the embankment and side tracks were badly washed out in places. Near Walker, Ind. T., 6 miles north of Purcell, about 3,900 feet of embankment, including both main and passing tracks, were demolished. The steel bridge over Canadian River near Walker was not damaged, but 385 feet of approach was washed out. Two miles farther south about 1,600 feet of embankment and a bridge went out. The main line was closed to traffic from 6 p. m. October 3 to 6 p. m. October 10.

The Missouri, Kansas and Texas Railway escaped with relatively little damage. At the crossing between Eufaula and Canadian, Ind. T., one bridge pier slipped on its base about 3 or 4 inches; the repairs cost $750. At the new bridge over the washed-out channel of 1898 about 150 feet of embankment south of the bridge was washed out and the south pier was undermined. On the recently completed line from Atoka to Oklahoma City no damage was done to the bridge at Tyrola, Ind. T., but the south approach was washed away and the

station grounds covered with sand. A large part of the line in the river valley was torn up.

The St. Louis and San Francisco Railroad lost 2,740 feet of a total of 3,130 feet of the bridge on the Blackwell, Enid and Southwestern branch near Golden, Okla. The cost of repairs was $20,000, and the traffic was suspended from October 2 to 25. On the line between Chickasha and Oklahoma City 490 feet of trestle approach was destroyed, the steel span remaining intact. The cost of repairs is estimated at $4,600. The traffic was suspended from October 3 to 15. At the Canadian River Bridge near Francis, Ind. T., about 140 feet of bridge was destroyed, costing in repairs $1,475, the traffic being interrupted from October 4 to 9.

Considerable damage was done to bridges on the Rock Island system, which crosses Canadian River at four different points. The steel bridge south of Union City, Okla., consisting of one steel through span and two girder spans, was completely carried away, the through truss being washed downstream several miles.

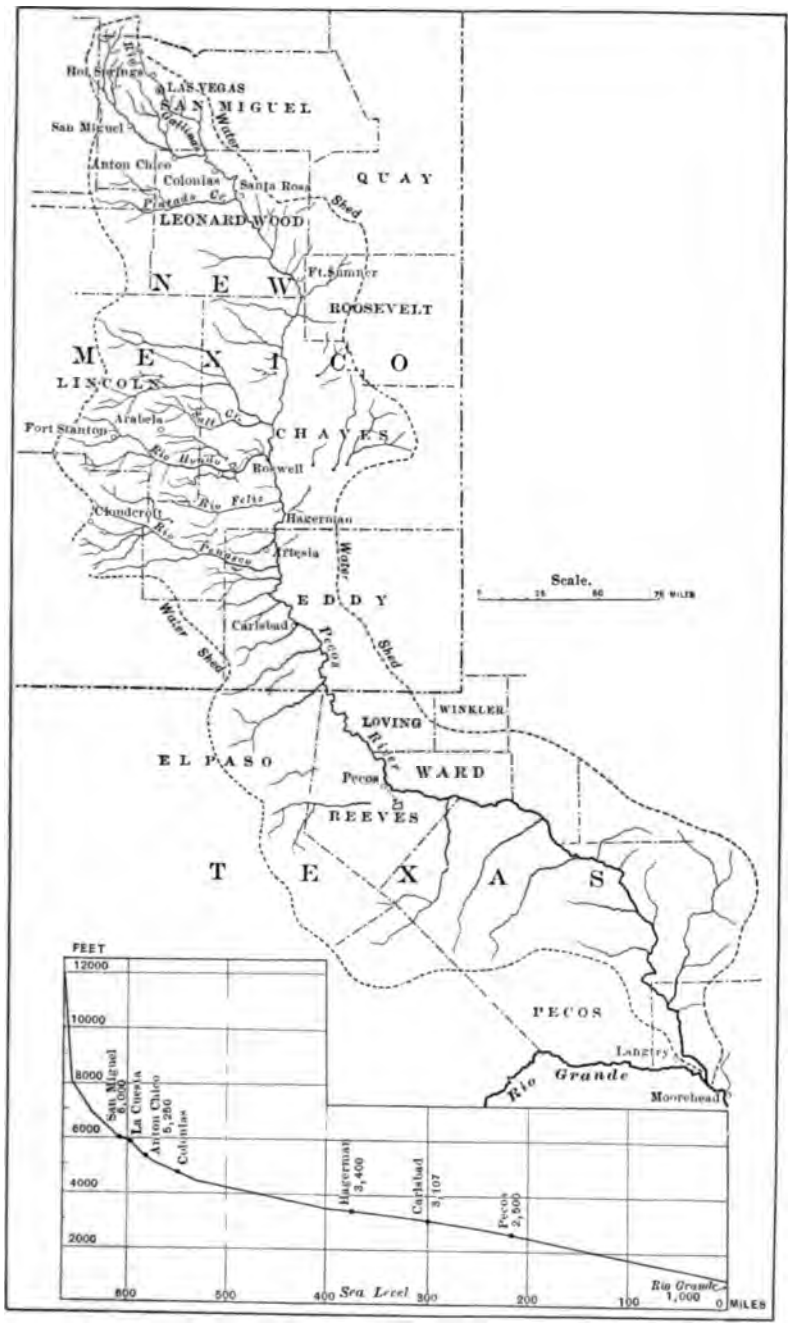
PECOS RIVER BASIN FLOOD, NEW MEXICO.[a]

During the latter part of September and the first part of October, 1904, there occurred upon the drainage basin of Pecos River the heaviest and most destructive flood in its recorded history.

STREAMS AND DRAINAGE BASIN.

Pecos River rises in the northern part of New Mexico, flows in a southeasterly and southerly direction for about 300 miles through New Mexico, thence for about 250 miles southeasterly through Texas, and empties into the Rio Grande near Langtry, Tex. The principal tributaries, all of which enter from the west, are Rio Peñasco, having a length of about 80 miles and a drainage area of 750 square miles; Rio Felix, having a length of 60 miles and a drainage area of 800 square miles; Rio Hondo, having a length of 90 miles and a drainage area of 1,900 square miles; Salt Creek, having a length of 80 miles and a drainage area of 2,550 square miles; Pintado Creek, having a length of 70 miles and a drainage area of 1,000 square miles; and Rio Gallinas, having a length of 50 miles and a drainage area of 620 square miles. These tributaries and the location of the gaging and precipitation stations are shown in Pl. X. The slope of the river is shown in the following table:

[a] Based on data obtained by personal observation during the flood and after it had subsided, by W. M. Reed, engineer, F. S. Dobson, engineering aid, and Geo. B. Monk, assistant hydrographer; prepared mainly from report by F. S. Dobson.



DRAINAGE BASIN AND PROFILE OF PECOS RIVER.

Profile of Pecos River, New Mexico.[a]

Locality.	Distance from mouth in miles.	Height above sea in feet.	Fall per mile in feet.
th	0	1,000	.....
s	215	2,550	7.2
'	300	3,107	6.6
erman	375	3,400	3.9
sing, Pecos River Railroad	405	3,500	3.3
ude 35°	530	4,600	8.8
Colonias	548	4,850	13.9
unta	556	4,950	12.5
	567	5,100	13.6
n Chico	577	5,250	15.0
uesta	597	5,800	27.5
Miguel	607	6,000	20.0
	622	6,500	33.3
	637	7,000	33.3
	657	8,000	50.0
l	663	12,000	666.7

annett, Henry, Profiles of rivers: Water-Sup. and Irr. Paper No. 44, U. S. Geol. Sur- 1901, p. 37.

bout 20,000 square miles of the drainage basin of this stream New Mexico, the greater portion being rolling sand hills, easily ivated, and very productive when irrigated. Along the eastern, ern, and northern edges of the basin are mountains, having s covered with snow all the year round. Above Santa Rosa below Roswell the valley is well developed, but between these s it is sparsely settled. South of Roswell there is an area of t 350,000 acres that will probably be eventually irrigated from sian wells.

he Pecos, as can be seen from the profile above, has a very steep e; its tributary streams also have steep slopes; consequently, flow of all is very rapid and destructive during time of flood.

PRECIPITATION.

he precipitation for September and October, 1904, measured by United States Weather Bureau at six places in this drainage n, was as follows:

Precipitation in Pecos River drainage basin, September and October, 1904.

Place.	Length of record.	September.		October.	
		Total precipitation.	Excess.	Total precipitation.	Excess.
	Years.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Arabela	2	9.95	.....	5.90	.....
Carlsbad	9	4.55	+3.45	1.71	+0.82
Cloudcroft	1	6.16	.....	4.37	.....
Fort Stanton	3	6.06	.....	2.68	.....
Las Vegas	17	6.07	+3.90	1.08	.00
Roswell	11	5.10	+3.06	2.67	+1.06

The precipitation during September varied from about 4.5 inches to 10 inches, which was 3 or more inches greater than the normal rainfall for this month. The precipitation for October was less than that for September, but was somewhat above the normal for October.

The following table gives the daily precipitation for the periods September 26 to 30 and October 5 to 8, 1904, and, taken in connection with the previous table, shows that more than half the September and October precipitation fell during these periods. The precipitation for twenty-four consecutive hours during these storms at five of these places was, as seen from the table, 2.7 inches or more.

As a result of these two periods of excessive precipitation, there was one large flood on this stream and a second somewhat smaller flood on some parts of it.

Daily precipitation in the Pecos River drainage basin September 26 to 30 and October 5 to 8, 1904, also the greatest precipitation in twenty-four consecutive hours.

Station.	Precipitation in 24 consecutive hours.	September—					
		26.	27.	28.	29.	30.	Total.
Arabela	2.70	T.	0.08	0.51	2.70	1.88	5.17
Carlsbad	2.69	.....	.....	.....	.95	.....	.95
Cloudcroft	2.80	0.10	2.80	1.40	.90	.....	5.20
Fort Stanton	2.86	T.	.....	1.00	2.00	2.86	5.86
Las Vegas	2.87	.05	.10	.26	2.87	1.77	5.05
Roswell	1.80	.....	.....	.42	.75	.....	1.17

daily precipitation in the Pecos River drainage basin, etc.—Continued.

Station.	Precipitation in 24 consecutive hours.	October—				
		5.	6.	7.	8.	Total.
la	2.50	.....	.....	1.13	2.50	3.63
bad	.38	.....	0.17	.09	.31	.57
croft	2.08	0.20	.20	1.00	2.08	3.48
Stanton	1.30	T.	.....	1.30	1.08	2.38
egas	.76	T.	.04	.76	.....	.80
ell	.80	.....	T.	.80	.60	1.40

FLOOD ON THE PECOS.

oods are not uncommon on the Pecos. They usually result from ing of snow, but occasionally, as in the present case, from y rains. There are five gaging stations on the main portion of stream and some on its tributaries. The stations on the main m are at Santa Rosa, Roswell, and Carlsbad, in New Mexico, Pecos and Moorehead, in Texas. From the gage-height records ined at these stations, the magnitude, duration, and to some it the progress of the flood down the river can be seen. Unfortely, however, the flood destroyed some of the gages, and also ged the channel of the river to such an extent at some of them the records are partly wanting or very poor.

daily gage height at gaging stations along Pecos River, September 27 to October 27, 1904.

Date.	Santa Rosa, N. Mex.	Roswell, N. Mex.	Carlsbad, N. Mex.	Pecos, Tex.	Moorehead, Tex.
mber 27	1.40	3.50	.....	.....	.....
mber 28	4.00	3.65	.....	.....	.....
mber 29	13.00	5.50	.....	.....	.....
mber 30	[a] 23.00	16.45	0.83	.....	.....
er 1	[a] 6.00	16.45	3.45	.....	.....
er 2	[a] 3.00	15.0	15.00	3.50	.....
er 3	[a] 3.00	.....	([b])	7.00	.....
er 4	[a] 2.00	.....	.....	9.00	.....
er 5	[a] 2.00	4.0	.....	19.00	.....
er 6	[a] 2.00	3.9	.....	17.00	.....
er 7	2.00	3.7	.....	15.50	1.60
er 8	2.00	.....	.....	13.00	2.10
er 9	2.00	6.45	.....	13.00	2.90
er 10	2.00	4.45	.....	11.00	3.30

[a] Estimated; gage washed away. [b] Gage washed out.

Mean daily gage height at gaging stations along Pecos River, 1904—Continued.

Date.	Santa Rosa, N. Mex.	Roswell, N. Mex.	Carlsbad, N. Mex.	Pecos, Tex.	Mourshead, Tex.
October 11	3.0	5.00	7.60	10.50	3.30
October 12	3.0	4.45	5.90	14.00	3.45
October 13				13.00	3.65
October 14				12.00	3.75
October 15				9.00	4.10
October 16				8.40	4.30
October 17				8.20	4.45
October 18				8.10	4.60
October 19				7.80	4.75
October 20				7.30	4.90
October 21				7.00	5.00
October 22					5.05
October 23					5.35
October 24					5.30
October 25					5.20
October 26					5.05
October 27					4.80

Measurements of flood cross sections and slope of bed were made at places along the Pecos and some of its tributaries, and the maximum discharge computed by Mr. F. S. Dobson by Kutter's formula. The following rates of flow were obtained: Pecos River at Fort Sumner 45,150 second-feet, at mouth of Salt Creek 45,350 second-feet, and at Roswell gaging station 55,690 second-feet; Salt Creek above mouth 12,400 second-feet; and Hondo River at gaging station near reservoir 6,330 second-feet. Mr. V. L. Sullivan, chief engineer of the Pecos Irrigation Company, estimated the flow of the Pecos at Lake Macmillan reservoir at the time the water began to pass over the rock spillway at 82,000 cubic feet per second.

The flood at Santa Rosa extended from September 28 to October 2, reaching a maximum on September 30, with a gage height of about 23 feet—that is, about 22 feet above low water. The estimated maximum discharge is 46,498 second-feet. There is little, if any, indication at this place of the second flood plainly seen in the records lower down the river.

Mr. W. G. Russell measured a cross section and the slope of the bed of the Pecos at Santa Rosa, October 26, 1904, and found the cross-section area to be 4,973 square feet, the velocity by Kutter's formula about 9.35 feet, and the maximum discharge 46,498 second-feet. The maximum stage above low water was about 23.4 feet.

A. DAM ON PECOS RIVER AT CARLSBAD, N. MEX., BEFORE THE FLOOD OF OCTOBER, 1904.

B. DAM AT CARLSBAD, N. MEX., AFTER THE FLOOD OF OCTOBER, 1904.

FLOOD AT DAM ON PECOS RIVER AT CARLSBAD, N. MEX., OCTOBER, 1904.

At Roswell the flood began on September 29 and continued until October 4, attaining a maximum on October 1, with a gage height of more than 17 feet and a discharge of about 55,690 second-feet. The surface fluctuations during this flood of Hondo River, which enters the Pecos near Roswell, are shown on page 139. The stage of the Hondo was a maximum at the gaging station at Hondo reservoir on October 5 at 5 p. m.

The flood at Carlsbad, as shown by the gage heights at Lake Macmillan, was at its maximum height 9.40 a. m. on October 2. (See Pls. XI, XII.) At Pecos the first flood reached a maximum stage on October 5 and the second on October 12. At Moorehead the maximum stage was not attained until October 23.

At Lake Macmillan, near Carlsbad, the following fluctuations of the Pecos during the flood were reported by Mr. V. L. Sullivan:

Gage height at Lake Macmillan, near Carlsbad, N. Mex., September 29 to October 2, 1904

Date.	Time.	Height in feet.
September 29	6 a. m	18.8
September 29	12 m	18.8
September 29	6 p. m	18.8
September 30	6 a. m	19.0
September 30	12 m	19.3
September 30	6 p. m	19.3
October 1	6 a. m	21.1
October 1	12 m	21.5
October 1	6 p. m	22.0
October 2	1.30 a. m	23.0
October 2	6.45 a. m	27.0
October 2	7.30 a. m	27.2
October 2	8.40 a. m	27.5
October 2	9.40 a. m	27.9
October 2	12.45 p. m	27.7

On October 3 Pecos River reached a stage of 7 feet at the United States Geological Survey gage near Pecos, and was slightly rising.[a] At 10 a. m. on October 4 the stage was increasing at the rate of about 1 foot per hour. At this time four breaks occurred in the Barstow Irrigation Company's levees, designed to protect the west valley lands from flood, at points about 3½ miles above the flume that carries the canal over Pecos River. Other breaks occurred later in the day, and on the morning of October 5 the water had a

[a] From report of Mr. Willard H. Denis, Barstow, Tex.

width of from one-half mile to 2½ miles on each side of the river and extended nearly to the foothills on each side of the valley, with a depth of from 2 to 4 feet. It had a reddish-gray appearance and a comparatively sluggish flow. Fortunately warnings had been given in ample time to permit the removal of stock to places of safety. The river continued to rise, and at 8 a. m. on October 6 reached a stage of 19 feet on the gage near Pecos. The water was above the base of the flume (see Pl. XIII), and its upward pressure, together with the downstream pressure of the water and the drift which collected against the flume, caused it to tear loose at the ends, break in two pieces, and float downstream. One of these parts, about 150 feet long, was afterwards found about 1¼ miles downstream; the other part, also about 150 feet long, floated about 6 miles downstream to the railway bridge, where it was again broken in two and passed on down the stream.

On October 15 the stage at the gage was again 9 feet; thus this flood, which swept through Roswell, N. Mex., in about three days, spread itself out to such an extent as to require about ten days to pass Pecos. On October 19, about two weeks after the beginning of the flood, most of the overflow water had found its way back into the river and passed downstream.

The water left a deposit of reddish clay and fine sand where it was sluggish and coarse sand where it was swift, of a depth generally of from 0.2 to 0.4 foot, but in some places of from 1 to 2 feet. In the west valley about two-thirds of the alfalfa was covered so deeply with silt or was submerged so long that it died. Some cotton, not all, in places was so deeply covered with sand as to be a complete loss. In all, 40 per cent of the cotton was saved, although the lands are generally lower than on the eastern side. Out of a total of 900 acres, about 700 were flooded.

On the east-valley side about a thousand acres of cultivated land was heavily, and as much more lightly, flooded. That in sorghum was badly injured, and from 25 to 50 per cent of the heavily flooded cotton was lost; while few plants were killed, except in little sags, many bolls were soaked until they soured.

At Riverton practically all crops, except on one farm, were lost, much sediment was left in the first mile of the main canal, the headgates were washed out, and all the laterals were destroyed.

Grand Falls escaped any material injury. The crest of the flood had become lower when it reached there, and most of the lands in use are on the second bench.

The following table gives the daily gage height obtained at the United States Geological Survey station near Pecos, Tex., during this flood:

FLUME OF BARSTOW IRRIGATION COMPANY, PECOS RIVER, TEXAS, CARRIED AWAY BY FLOOD OF OCTOBER 5, 1904.

Gage height, in feet, of Pecos River near Pecos, Tex., October 2 to 21, 1904.

October 2	3.50
October 3	7.00
October 4	9.00
October 5	19.00
October 6	17.00
October 7	15.50
October 8	13.00
October 9	13.00
October 10	11.00
October 11	10.50
October 12	14.00
October 13	13.00
October 14	12.00
October 15	9.00
October 16	8.40
October 17	8.20
October 18	8.10
October 19	7.80
October 20	7.30
October 21	7.00

The flood thus reached a maximum stage on October 5, with a gage height of about 19 feet, or a height above low water of about 18 feet. The gage read 9 feet or more for twelve consecutive days.

The following table gives the daily gage height and corresponding discharge at Moorehead, Tex., near the mouth of the river, during this flood. The river at this place began to rise on October 8, reaching a maximum on October 23. At Santa Rosa the flood lasted from September 28 to October 3—that is, about four days—reaching a maximum above low water of about 22 feet. At Moorehead, 520 miles down the stream from Santa Rosa, it lasted from October 8 to beyond October 27, attaining a maximum height on October 23 of 4 to 5 feet above low water.

Gage height and discharge of Pecos River at Moorehead, Tex., October 7 to 27, 1904.

Date.	Height in feet.	Discharge in second-feet.	Date.	Height in feet.	Discharge in second-feet.
October 7	1.60	590	October 18	4.60	3,680
October 8	2.10	[a] 700	October 19	4.75	4,040
October 9	2.90	1,260	October 20	4.90	4,410
October 10	3.30	1,740	October 21	5.00	4,660
October 11	3.30	1,740	October 22	5.05	4,790
October 12	3.45	1,830	October 23	5.35	[a] 5,577
October 13	3.65	2,050	October 24	5.30	5,460
October 14	3.75	[a] 2,095	October 25	5.20	5,220
October 15	4.10	2,630	October 26	5.05	4,880
October 16	4.30	3,010	October 27	4.80	4,360
October 17	4.45	[a] 3,340			

[a] Obtained with current meter.

FLOOD ON GALLINAS RIVER.

During the night of September 29, while the flood was at its height, four timber dams on Gallinas River above Las Vegas and Hot Springs were washed out, liberating about 6 acre-feet of water. The timbers from these dams formed a temporary dam in front of the trestle of the upper bridge at Hot Springs and forced out the bridge about 1 a. m. September 30. The volume of water, headed by the timber from the dam, took out two more footbridges, the end of the bath house, all the masonry protection wall above the main span bridge at the railway station, and 50 feet of masonry wall below the bridge. Between Hot Springs and Las Vegas, 6 miles down the valley, three railway bridges were washed out and the railway tracks were more or less damaged. At Las Vegas the railway station for the Hot Springs branch, a large frame structure situated on the left of the bank, was completely taken out by the erosion of the bank. An adjoining building, belonging to the Moore Lumber Company, was damaged to a considerable extent and considerable lumber lost.

The greater portion of all the damage at Hot Springs and at Las Vegas was undoubtedly due to the obstruction formed by the temporary wooden dam against the trestle of the bridge at Hot Springs.

The amount of damage sustained by the Agua Pura Company, which owned the timber dams that were destroyed, is estimated to have been from $5,000 to $8,000; the damage at Hot Springs is estimated to have been about $10,000, and to the town of Las Vegas about $25,000.

The following are readings of the gage at Hot Springs before it was destroyed by the flood:

Gage height, in feet, at Hot Springs, N. Mex., 1904

September 29, 7 a. m.	2.50
September 29, 9 a. m.	4.00
September 29, 12 m.	3.50
September 29, 5 p. m.	4.00
September 29, 9 p. m.	5.00

September 29, 11 p. m., the first rush of water came down the stream.
September 30, 12.30 a. m., temporary timber dam formed in front of bridge.
September 30, 1 a. m., the temporary dam in front of bridge was swept away.

The maximum discharge of this stream was computed from Kutter's formula by Mr. Monk, using a cross section of the stream about 200 yards below the gaging station. The slope was found to be 0.0041 feet per foot, area 1,534 second-feet, wetted perimeter 212 feet. With these data and the value of the coefficient of roughness $n=0.05$, the maximum discharge was found to be 11,612 second-feet. This rate of flow continued for about one hour. At 8 a. m. on September 30 the river had fallen so that its discharge was about 700 second-feet, and on October 11 its discharge was 135 second-feet.

:otal discharge from September 29 to October 7, inclusive, an be considered the flood period of this stream at this place, ınd to be 16,572 acre-feet, from a drainage area of 90 square This means an average depth of 3.44 inches over this area, un-off per square mile during the nine days of the flood of cond-feet.

:hannel through Las Vegas is very crooked and causes the › rush from one bank to the other, and as there were no protec- lls on either bank considerable erosion took place.

FLOOD ON HONDO RIVER.

'ollowing table gives the daily gage height and approximate ge of Hondo River at the reservoir 12 miles southwest of , N. Mex., and at the gaging station at Roswell. The maxi- scharge is very uncertain as the stream overflowed its banks onsiderable part of the discharge passed around the gaging

ght and discharge of Hondo River at Roswell and near the reservoir, September 27 to October 15, 1904.

Date.	Roswell.		Reservoir.	
	Gage height in feet.	Discharge in second-feet.	Gage height in feet.	Discharge in second-feet.
er 27	0.00	0.00	1.15	14
er 28	2.25	.62	5.50	370
er 29	3.60	2.24	2.30	70
er 30	([a])		9.60	4,400
1	([a])		10.16	6,290
2	2.35	70	1.80	33
3	1.65	29	1.15	14
4	1.50	23		
5	1.30	15		
6	1.25	13		
7	1.75	34		
8	4.80	[b] 520		
9	4.35	[b] 365		
10	4.50	[b] 415		
11	3.25	171		
12	2.70	103		
13	2.10	52		
14	1.90	41		
15	1.75	34		

[a] Banks overflowed; gage not read.
[b] No allowance made for overflow water passing around the station.

There were two floods on this stream in October, one reaching a daily maximum on October 1, with a gage height at the reservoir gaging station of 10.16 feet, and the second one reaching a maximum on October 8, with a gage height at Roswell of about 4.8 feet. The second flood was of longer duration than the first, but did not reach as great a stage. On October 1 the water at the gaging station near the reservoir was 1.5 feet above the floor of the bridge from which the discharge measurements are usually made; hence a considerable portion of the discharge must have passed around the gaging station.

The following table gives the gage height of Hondo River at the gaging station near the Hondo reservoir:

Gage height on Hondo River near the reservoir, September 29 to October 9, 1904.

Date.	Time.	Height in feet.	Date.	Time.	Height in feet.
September 29	6 p. m.	2.20	October 7	8 a. m.	0.80
September 30	9 a. m.	9.00	October 7	7 p. m.	5.30
September 30	6 p. m.	10.20	October 8	6 a. m.	9.15
October 1	5 a. m.	9.60	October 8	6.30 a. m.	9.48
October 1	5.30 a. m.	9.70	October 8	10 a. m.	10.64
October 1	11 a. m.	10.20	October 8	2 p. m.	10.13
October 1	2 p. m.	10.20	October 8	4 p. m.	9.70
October 1	5 p. m.	10.50	October 8	5 p. m.	10.30
October 1	6 p. m.	9.20	October 9	8 a. m.	9.20
October 2	6.30 a. m.	2.00	October 9	5 p. m.	6.90

DAMAGE DONE BY FLOOD.

At Las Vegas and vicinity the Santa Fe Railway bridge was destroyed; loss, $10,000. The irrigation company had two or three dams washed away and ditches damaged; loss, $15,000. In Las Vegas itself the damage was estimated at $25,000.

At Roswell the damage was estimated at $15,000. The whole of the business part of the city was under water on September 30 and October 1, and again on October 8 and 9. Many adobe houses were destroyed.

At Carlsbad the Pecos Valley and Northeastern Railway bridge, the Green street highway bridge, and the La Huerta highway bridge were destroyed. The Lake Avalon dam was destroyed and Lake Macmillan and Carlsbad dams badly damaged. The total damage in and around Carlsbad is estimated at $100,000. (See Pls. XI, XII, p. 134.)

Considerable silt was deposited in the low valley. In some places

this deposit is 2 to 3 feet in depth, but it resulted in little damage, as it was not deposited on farming land.

PREVENTION OF FUTURE DAMAGE.

Floods of great magnitude occasionally occur on this stream and are very destructive to irrigation interests on account of the great slope of its bed. They destroy the dams or cut channels around them, destroy the headgates of canals or form bars in front of them, overflow the irrigable land, deposit immense quantities of silt, sand, and gravel, and in some cases bowlders, filling the canals and covering the land.

The apparent remedy is to store the flood waters. The topography of the country renders storage easy, and the demand for the water for irrigation will add to the value resulting from prevention of overflow.

FAILURES OF LAKE AVALON DAM NEAR CARLSBAD, N. MEX.

By E. C. Murphy.

Two failures of the Lake Avalon dam have occurred within a dozen years. The dam is located on Pecos River, about 6 miles above the town of Carlsbad, N. Mex., and was built to form a storage reservoir for irrigation purposes. The dam, as reconstructed after the first failure, was a composite structure of loose rock with earth on the upstream side. The total length was 1,380 feet and the maximum height 48 feet. The loose-rock part had a top width of 10 feet, inside slope ½ to 1, laid by hand; downstream slope 1½ to 1, laid by hand. The earth part had a top width of 10 feet and a slope of 3½ to 1, riprapped 1 foot thick.

The right bank of the river at the dam is a conglomerate, the left bank is limestone, and the river bed is mixed well. The loose rock used in the dam was the conglomerate taken from the right bank. It is mainly chunks 6 to 18 inches in diameter, with much fine material. It was dumped in place by carts. The earth used was a sandy loam containing some clay, obtained near the dam. It was put in place with carts and scrapers and consolidated by the travel of teams and vehicles over it.

There are three wasteways, one at each end and the other on the right bank about one-half mile from the dam. The principal one was located on the limestone ledge on the right bank and was provided with gates. Its discharge capacity for a water height of 23 feet, or 7 feet below the crest of the dam, was 16,900 second-feet. Spillway No. 1 had a capacity of 5,600 second-feet; No. 2, 7,300

second-feet; headgates of canal, 3,200 second-feet. The total discharge of the wasteways when the water surface in the lake was 7 feet below the crest of the dam was 33,000 second-feet.

The reservoir when filled to the 23-foot level had a length of about 5 miles and a maximum width of 1½ miles; it submerged an area of 1,980 acres and had a capacity of 6,300 acre-feet.

The dam was built in 1894 on the site of the composite loose rock and earth dam that failed during the flood of August, 1893, when the maximum discharge of Pecos River at this place was 43,000 second-feet. The first dam had a lighter cross section than the second and had only one spillway.

The second failure occurred at 11 p. m. October 1, 1904, during a flood of unprecedented magnitude, the rate of flow at this place being, according to the estimate of Mr. V. L. Sullivan, engineer of the Pecos Valley Irrigation Company, 82,000 second-feet. It failed by the water forcing a passage through the dam, not by flowing over the top, but the height above the bed where the earth facing failed could not be ascertained.

Mr. F. G. Tracy, president of the Pecos Valley Irrigation Company, was at the dam at the time of its failure, and states that the water reached a height of about 3 feet below the crest of the dam and remained nearly stationary for a few hours. He thought the danger of failure was over, but shortly after the lake surface at the dam dropped rapidly 3 feet.

He went out on the dam with a lantern and heard the water roaring through the dam, but the crest had not settled. The water continued to fall for some minutes and then appeared to rise for a short time, after which the dam gave way. A section about 450 feet long at the crest and 400 feet at the base was washed out.

There are two opinions as to the cause of the failure. One is that animals burrowed into the earth facing from the downstream side and weakened it; the other is that the failure occurred near the base at the right end. There was some leakage at the latter point, and efforts were made to stop it by sheet piling, but without complete success. Whether the failure was due to animals burrowing or to faulty construction of the dam at the right bank can not be ascertained, as it occurred in the night.

The flood waves caused by both failures were large. At the first one in August, 1893, all bridges in Carlsbad and the flume that carried water for irrigation across Pecos River were swept away. The flood at the second failure damaged the flume, swept away the three bridges, cut a new channel around the dam at Carlsbad, and eroded the river banks to a considerable extent. It is said that the channel

in the vicinity of Carlsbad is twice as wide at the present time as prior to the flood of 1893.

Nine miles above Lake Avalon dam is located Macmillan dam, a somewhat larger composite structure having a maximum height of 52 feet and a crest length of 1,686 feet. The side slopes and top width are the same as those of Lake Avalon dam, but the top width of the loose-rock part of the larger structure is 14 feet and of the earth part 6 feet. This dam was not damaged by the flood, but fears were entertained for its safety, as its spillways were raised a few feet a short time prior thereto.

The writer is indebted to Mr. B. M. Hall, supervising engineer, United States Reclamation Service, and to Messrs. F. G. Tracy, H. Christian, and V. L. Sullivan, officers of the Pecos Valley Irrigation Company, for some of the information used in the preparation of this paper.

RIO GRANDE FLOODS, NEW MEXICO.

By E. C. Murphy.

During the latter part of September and the early part of October there were frequent and at times quite heavy rains in Texas and southern New Mexico that caused the Rio Grande to overflow its banks at some places. The property loss due to these overflows was not large.

PRECIPITATION.

The precipitation recorded at six places in this drainage basin from September 28 to October 15, 1904, was as follows:

Precipitation in Rio Grande basin, 1904.

	Inches.
Taos	2.88
Albuquerque	1.03
Los Lunas	4.15
Socorro	5.48
San Marcial	2.50
Mesilla Park	2.86

FLOOD IN SOUTHERN NEW MEXICO.

The following table gives the mean daily gage height and corresponding discharge of the Rio Grande during these floods at three of the gaging stations on it, and from this table the magnitude and duration of the floods can be seen. One of these stations is at Cenicero, Colo., near the Colorado-New Mexico boundary line; another is at San Marcial, N. Mex., about 145 miles north of El Paso, Tex., and the other is near El Paso.

Daily mean gage height and discharge of Rio Grande, 1904.

Date.	Cenicero, Colo.		San Marcial, N. Mex.[a]		El Paso, Tex.[a]	
	Gage height in feet.	Discharge in second-feet.	Gage height in feet.	Discharge in second-feet.	Gage height in feet.	Discharge in second-feet.
September 27	1.10	84	9.10	950	4.70	110
September 28	[b] 1.10	84	[b] 10.40	3,030	5.35	280
September 29	1.20	112	10.50	3,280	5.80	500
September 30	1.50	236	11.70	7,550	6.05	620
October 1	[b] 2.90	556	11.95	8,550	7.45	1,730
October 2	3.00	1,865	13.10	18,400	9.55	4,040
October 3	[b] 2.95	1,800	[b] 12.70	19,070	10.80	5,410
October 4	3.00	1,865	9.50	5,000	11.55	6,230
October 5	2.90	1,735	[b] 8.90	3,200	12.10	6,850
October 6	2.70	1,480	8.60	2,600	12.75	8,170
October 7	[b] 2.60	1,355	9.10	3,000	11.50	6,180
October 8	2.90	1,735	8.95	2,880	11.10	5,740
October 9	3.30	2,125	11.55	12,000	12.55	7,670
October 10	[b] 3.75	2,860	[b] 12.85	24,000	13.30	11,370
October 11	3.95	3,150	13.75	33,000	13.15	10,550
October 12	3.95	3,150	[b] 10.60	24,800	13.40	12,010
October 13	[b] 3.70	2,790	9.45	21,720	13.60	13,800
October 14	3.50	2,520	9.00	15,900	13.90	16,200
October 15	3.20	2,125	8.90	11,100	13.95	17,100
October 16	3.20	2,125	8.75	6,250	11.35	9,300
October 17	[b] 3.00	1,865	8.65	1,550	10.35	6,300
October 18	3.00	1,865	8.65	1,710	9.85	5,050
October 19	2.90	1,735	8.55	1,770	9.55	4,300
October 20	2.80	1,605	8.40	1,780	9.25	3,550
October 21	[b] 2.60	1,355	8.20	1,730	9.05	3,150
October 22	2.60	1,355	8.30	1,750	8.80	2,700
October 23	2.50	1,230	8.25	1,620	8.65	2,460
October 24	2.50	1,230	8.10	1,390	8.50	2,250
October 25	[b] 2.40	1,110	8.15	1,370	8.65	2,460
October 26	2.20	874	8.20	1,430	8.35	2,040
October 27	2.10	762	8.10	1,240	8.15	1,800

[a] Results furnished by W. W. Follett, consulting engineer International Boundary Commission.

[b] Meter measurements.

The record at Cenicero, Colo., shows two maximum stages—one October 2 to 4 of 3 feet, and another on October 11 and 12 of 3.95 feet. As the stage at this station is occasionally 6 feet higher than

either of these stages, it is evident that these floods were almost entirely south of the Colorado-New Mexico boundary line.

The record at San Marcial shows that the Rio Grande at this place reached a maximum stage of 13.1 feet with a discharge of 18,400 second-feet on October 2 and a stage of 13.75 feet and discharge of 33,000 second-feet on October 11. The second of these floods was much larger and of longer duration than the first, and the discharge for four consecutive days during the second was larger than at any time during the first. It is interesting to note the effect of the sandy bed of the stream at this place on the height of the flood. Although the discharge on October 11 was 80 per cent greater than on October 2, the gage height was only 0.65 foot greater on the earlier date. If the bed had been rock or permanent material, the extent of overflow would have been much greater than it was.

At El Paso, Tex., the stream reached a maximum stage on October 6, with a gage height of 12.75 feet and a discharge of 8,170 second-feet, and on October 15 it reached a stage of 13.95 feet with discharge of 17,100 second-feet. For seven consecutive days during the second flood the discharge at El Paso was greater than at any time during the first.

The following table gives the mean daily discharge of the Rio Grande at seven places on it and of the Pecos, near its mouth, for October, 1904, while the streams of New Mexico, Texas, and Mexico were in flood:

Mean daily discharge, in second-feet, of Rio Grande and Pecos River, October 1 to 31, 1904.[a]

Date.	Rio Grande.					Pecos River at Moorehead.	Rio Grande.	
	San Marcial.	El Paso.	Upper Presidio.	Lower Presidio.	Langtry.		Below Devils River.	Eagle Pass.
October 1	8,550	1,730	0	7,770	11,350	980	17,000	15,400
October 2	18,400	4,040	0	6,200	9,250	1,150	15,510	14,640
October 3	19,070	5,410	0	3,920	9,100	890	15,060	11,880
October 4	5,000	6,210	0	4,100	9,250	760	13,960	10,430
October 5	3,200	6,850	0	4,450	8,050	715	12,560	11,600
October 6	2,600	8,170	0	3,750	6,400	675	12,810	9,280
October 7	3,000	6,180	300	4,630	6,100	590	13,510	8,640
October 8	2,880	5,740	1,300	7,600	5,800	700	11,300	8,470
October 9	12,000	7,670	1,750	7,950	5,800	1,260	10,640	8,800
October 10	24,000	11,370	2,090	7,080	6,850	1,740	10,880	8,800
October 11	33,000	10,550	2,600	8,830	10,600	1,740	13,370	10,000
October 12	24,800	12,010	3,540	12,680	12,850	1,830	14,060	13,900

[a] Data furnished by W. W. Follett, consulting engineer.

Mean daily discharge, in second-feet, of Rio Grande and Pecos River, October 1 to 31, 1904—Continued.

Date.	Rio Grande.					Pecos River at Moorehead.	Rio Grande.	
	San Marcial.	El Paso.	Upper Presidio.	Lower Presidio.	Langtry.		Below Devils River.	Eagle Pass.
October 13	21,750	13,800	4,200	16,700	14,650	2,050	14,440	15,400
October 14	15,900	16,200	4,000	17,100	19,300	2,095	20,360	20,800
October 15	11,100	17,100	3,630	18,300	21,250	2,630	28,880	31,000
October 16	6,250	9,300	6,180	18,900	19,150	3,010	24,880	29,600
October 17	1,550	6,300	9,360	18,500	21,100	3,340	25,880	28,560
October 18	1,710	5,050	8,910	17,500	21,400	3,680	25,480	28,420
October 19	1,770	4,300	8,910	15,900	25,300	4,040	29,500	29,170
October 20	1,780	3,550	7,000	13,920	20,050	4,410	26,740	31,420
October 21	1,730	3,150	7,000	12,480	18,700	4,660	21,980	28,420
October 22	1,750	2,700	8,550	10,900	19,750	4,790	21,620	26,580
October 23	1,620	2,460	6,350	10,020	16,900	5,570	19,860	26,780
October 24	1,390	2,250	3,540	8,270	14,800	5,460	17,900	25,090
October 25	1,370	2,460	2,410	6,870	13,750	5,220	16,320	25,640
October 26	1,430	2,040	2,240	6,180	12,700	4,880	16,020	21,720
October 27	1,240	1,800	2,240	5,490	10,300	4,360	15,870	19,240
October 28	1,200	1,620	2,010	7,050	8,800	3,520	14,970	16,800
October 29	1,160	1,620	1,800	8,100	8,650	2,780	14,370	15,160
October 30	1,120	1,620	3,540	9,150	9,550	2,620	14,220	13,980
October 31	1,230	1,500	2,010	6,700	11,500	2,130	13,920	15,160
Mean	7,534	5,960	3,403	9,903	13,194	2,719	17,544	18,735

Fig. 13 shows the location of the above gaging stations.

The following facts may be noted. The flood at San Marcial that had a maximum discharge on October 3 of 19,070 second-feet produced a maximum three days later at El Paso of only 8,107 second-feet. The second flood reached a maximum at San Marcial of 33,000 second-feet on October 11 and a maximum four days later at El Paso of 17,100 second-feet. These two stations are about 145 miles apart. There are a number of small streams entering between the stations, but no large ones.

The Rio Conchos enters the Rio Grande between the upper and lower Presidio stations, and to it is due the difference in the discharge at the two places. Up to October 7 the Rio Grande was dry above the mouth of the Conchos, the flow at El Paso, which varied from 1,730 to 6,210 second-feet from October 1 to 4, failing to cause a flow at this place, although they are only about 220 miles apart.

The volume of flow of the Rio Grande at Devils River station

should be approximately the sum of the volumes of flow at Langtry, of the Pecos at Moorehead, and of Devils River, which is 16,483 as compared with the measured amount of 17,544 second-feet.

There is a gaging station on Devils River near its mouth, but its discharge is not given in the table, as it was nearly constant during

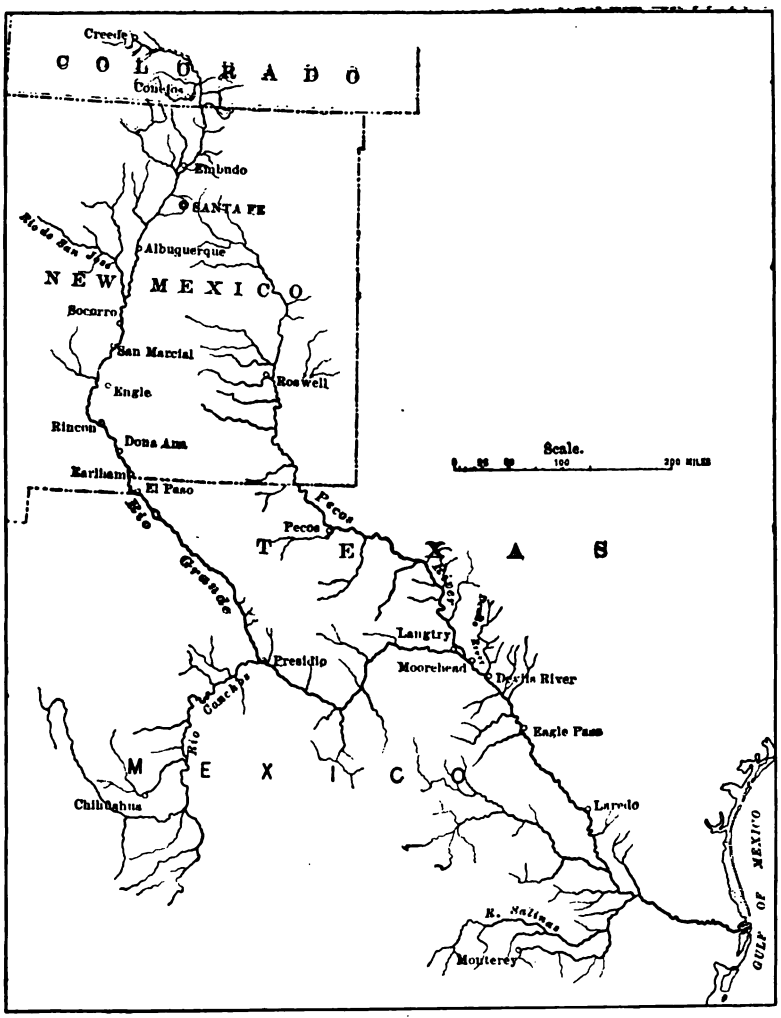


FIG. 13.—Drainage basin of the Rio Grande.

the month, varying only from 530 to 610 second-feet, the mean for the month being 570.

The flow of the Rio Grande at Eagle Pass for the month was somewhat larger than that at the station just below the mouth of Devils River, owing to the discharge of certain small tributaries entering between these places.

FLOOD IN NORTHERN AND CENTRAL NEW MEXICO.

A measurement made at the gaging station at Rio Grande, N. Mex., on September 29 showed a discharge of 606 cubic feet per second, with the water surface 14.05 feet below the floor of the railway bridge. Late in the afternoon of that day the river began to rise and at 11 p. m. had reached its maximum stage, 7.6 feet above the stage at which the measurement had been made. A measurement with surface floats was made at 6 o'clock the next morning, with the stage about 1 foot below maximum, and the discharge found to be approximately 28,000 cubic feet per second. At 6 a. m. October 1 a measurement was made and the discharge found to be 2,500 cubic feet per second. The cross section of the stream at this gaging station was found to have been greatly changed by the flood. The maximum discharge at this place was computed to be 30,936 cubic feet per second, and the total volume of run-off from September 29 to October 10, inclusive, 131,782 acre-feet, from a drainage area of 11,250 square miles.

The maximum discharge was also computed by Mr. Monk, using Kutter's formula, with a coefficient of roughness $n=0.025$, and a surface slope $S=0.0007$ feet per foot, and found to be 19,567 cubic feet. It is seen that the discharge, as obtained by the formula, is 30 per cent less than that obtained by the floats. This is probably due to the difficulty of measuring the surface slope.

Albuquerque Valley from the mouth of White Rock Canyon to San Marcial varies in width from one-fourth mile to 3 miles, most of which is under cultivation. As this valley is comparatively flat and very slightly above the level of the river channel, the water spread and covered nearly all of it. The widening of the stream diminished its force and consequently the damage to buildings was very small, but almost the entire harvest of corn, wheat, and oats was destroyed and the orchards and vineyards damaged to a large extent. The soil, however, was enriched by the sediment and benefited by the washing of the alkali from the land. The town of Albuquerque was affected by the flood to only a slight extent other than the suspension of railway traffic for about ten days. At San Marcial the levees east of the town broke at 6 p. m. on October 2 and allowed the water to reach the town. In the Mexican quarter of the town 70 houses were rendered uninhabitable, and about 280 people were obliged to seek refuge with friends or in tents. The water in the streets varied in depth from 1 to 2 feet.

The precipitation at Santa Fe, N. Mex., on September 29 and 30 was 2.51 inches, about 0.8 inch greater than for any previous two days' record. This precipitation caused a very large flood in the Santa Fe canyon in the bed of a small stream that is usually dry.

The flood on this stream reached the storage reservoir at Santa Fe t 8.30 p. m. on September 29, and at 10 p. m. had filled the reser-oir (200,000,000 gallons capacity) and was running over the spill-vay to a depth of 36 inches. From this time until 2 a. m. on Sep-ember 30 the river was discharging approximately 750 cubic feet er second. For the following twenty-four hours the discharge fluc-uated between 500 and 200 cubic feet per second, then decreased to flow of 35 cubic feet per second, which stage it maintained for bout ten days. It then gradually decreased to zero on October 25.

The flood as it appeared just above the Santa Fe reservoir is lescribed by an eyewitness as a wall of water 8 feet high with a elocity of about 20 miles per hour.

From the first water on September 29 to October 10 the estimated lischarge of this usually dry stream was 1,636 acre-feet, after stor-ng in the city reservoir 614 acre-feet.

The Santa Fe Light and Water Company sustained the heaviest oss, which amounted to between $3,000 and $5,000. The main water ipe into its power house was broken, leaving the city of Santa Fe vithout water and light for about forty-eight hours. One of its ridges was washed out and four others were more or less damaged. Other damages were of minor importance.

DAMAGE DONE BY FLOOD.[a]

The damage done by this flood consisted of: (1) Loss of crops on the area overflowed, consisting of alfalfa, corn, beans, and vegetables. (2) Damage to land along the river that in some places had the soil washed away and in other places was covered with sand. (3) Damage to dams, head-gates of canals, and irrigation ditches. (4) Destruction of houses; many of the houses in this section of the country are built of adobe, and the water soon softened the clay and the houses fell. (5) Damage to highways and railway bridges along the river, some of which had one or more spans taken away by the flood.

Summary of losses from Engle, N. Mex., to El Paso, Tex.

Las Palomas Valley	$315
Near Arrey, west side Rio Grande	1,645
Lands under sand, San Isidro canal	5,380
Colorado and Rodey settlers	1,930
Southwest of Rincon	2,195
Dona Ana community	1,200
Las Cruces district	9,460
Near Earlham	5,080

[a] Taken mainly from report of J. L. Rhead, assistant engineer.

Near Berino and Anthony	$8,210
Santo Tomas and San Miguel communities	1,135
La Mesa community	7,000
Chamberino	4,555
Near El Paso, Tex	6,100
Total	54,265

FLOODS IN THE DENVER DISTRICT.[a]

By M. C. Hinderlider and assistants.

REVIEW OF YEAR.

INTRODUCTION.

The year 1904 has passed into history as one of great and destructive floods, this being particularly true of portions of the arid and semiarid sections of the Rocky Mountain districts, in numerous parts of which there have occurred, almost without warning, ruinous floods, which swept everything before them and left wreck and ruin in their wake. What had for years been known only as dry gulches, or arroyos, were suddenly converted into torrential streams, laying waste entire villages, destroying crops, sweeping away homes, drowning live stock and, in some instances, human beings.

Some of the floods were remarkable for the suddenness of their occurrence and the corresponding rapidity of their dissipation and the havoc wrought, others by their occurrence in localities where even more destructive floods had occurred the previous year, others for length of duration, and still others for fearful loss of life which shocked the whole country.

In Colorado there occurred early in the spring a flood of large proportions along the valley of Cache la Poudre River, which, owing to its location in what is probably the most intensely cultivated and valuable agricultural section of the State, caused heavy losses both to individuals and to the towns of Livermore, Fort Collins, and Greeley, and also to railway and ditch corporations; one life was lost. The same storm, precipitating also on the headwaters of Crow Creek, in southern Wyoming, caused that stream to rise to an excessive height within a few hours, resulting in the destruction of a great deal of private and corporate property in Cheyenne, Wyo., and the loss of two lives. A detailed report of this flood, compiled from reports by Messrs. James J. Armstrong, irrigation engineer, and A. J. Parshall, resident hydrographer, appears on pages 156–158.

Doubtless the most destructive flood of the year in Colorado, if

[a] On account of lack of space it has been necessary to condense certain parts of this report and to omit other parts of minor importance; it has also been found impossible to reproduce many of the accompanying illustrations.—E. C. Murphy.

judged by the extent of the financial losses, was that along Las Animas, or Purgatory, River, a southern tributary of the Arkansas. This occurred on October 1 and resulted in heavy losses to railway corporations and to the city of Trinidad. A detailed report of this flood, by R. I. Meeker, assistant engineer, appears on pages 158–169.

Another flood whose results were particularly direful was that of August 7, which occurred in what is ordinarily a dry tributary of Fountain River, and caused the awful Eden disaster on the Denver and Rio Grande Railroad, in which 106 people lost their lives.

During the latter part of September very heavy rains, resembling cloud-bursts, occurred in northeastern New Mexico, causing the Gallinas, Sapello, and Mora rivers to overflow their banks and flood their valleys, and resulting in the destruction of an enormous amount of property and the loss of several lives. Heavy floods on the Rio Grande in this territory were a feature of the season's flood conditions. A destructive flood occurred in La Plata Valley, in New Mexico, on October 6, a detailed account of which is given by Mr. T. Tobish, field assistant, on pages 169–171.

Destructive floods occurred also along Canadian River and Ute Creek, in northeastern New Mexico, and along the Rio Pecos, in the eastern part of the territory, resulting in heavy damage to the Chicago, Rock Island and El Paso Railroad and to the residents along these streams. These floods have been reported by Mr. W. G. Russell, resident hydrographer, of Russell, Kans., and Mr. W. M. Reed, engineer, at Roswell, N. Mex.

FLOOD STATIONS.

In the spring of 1904, in response to the general desire of the people of Kansas for a Federal investigation of flood conditions in that State, eight river observation stations were established on the streams most generally affected by floods, at points where records of their stage could be secured. In locating these, several things had to be considered, among them the necessity for placing them at points where the records would be of the most value to the residents of the cities and agricultural districts farther down the river, and at points where they might be within easy reach of telegraph or telephone accommodations for transmitting warnings of high and dangerous stages to residents along the lower course of the streams. After due consideration, the following points were selected: Fall River at Fallriver, Kansas River at Solomon, Kansas River at St. George, Kansas River at Topeka, Neosho River at Neosho Rapids, Neosho River at Humboldt, Verdigris River at Independence.

At each of these stations permanent gages were established, observers employed to make the observations, the river channel cross

sectioned, levels of previous high-water stages taken and connected with permanent bench marks, slopes of channel secured, and information collected regarding the character and damage resulting from previous floods.

The observers were instructed to take daily readings after the stage of the river rose above a certain point, to take such readings hourly, if necessary, during dangerous rises, and to report the same to towns lower down the river. These observations of river stage proved of great value, particularly to the agricultural districts, as the information concerning dangerous rises enabled the farmers to transfer their stock to places of safety before the appearance of a flood. This information during the spring and summer of 1904 prevented losses to the farming communities along Fall River aggregating many thousands of dollars. The telephone companies cooperated in this work by transmitting all messages free of charge. In Colorado, Kansas, New Mexico, and Wyoming the various railway companies extended valuable assistance in the collection of flood data and other furtherance of this work. Some of the data obtained at these flood stations are given in the discussion of floods in southeastern Kansas, pages 59–113.

CAUSE OF FLOODS.

The cause of the floods in this district has been mainly abnormal rainfall for a short period of time over comparatively small areas. In some cases the failure of artificial works on the stream has increased the flood flow and the destruction wrought.

The flood discharge of a stream is controlled by two factors, viz, rate of run-off from drainage basin and capacity of the channel. If either of these controlling factors can be regulated, the other may be disregarded. To regulate the run-off one requirement is necessary, viz, storage. This may be either natural or artificial in character or both. If natural, the storage will consist of the forest covering of the drainage basin, the character of the soil, and the topography; if artificial, the water must be stored in reservoirs. If, on the other hand, the run-off can not be controlled by storage, the drainage channel must be maintained at such capacity as to accommodate the maximum run-off in the minimum length of time. It sometimes happens that the natural channel is of sufficient capacity to meet the requirements, but this is not often the case; more frequently it is crooked, with banks lined with brush and timber, and more or less obstructed by débris and dams, which change the natural grade of the river, and by low-spanning bridges, piers, and abutments, loose riprap, and other serious encroachments on the banks such as are generally found in cities where the river banks are made the dumping ground for the city garbage.

DAMAGE DONE BY FLOODS.

The data in the accompanying reports illustrate the great destruc-iveness of floods. As an instance of their suddenness when resulting 'rom the so-called cloud-bursts may be cited the case in Colorado, in vhich an entire train load of unsuspecting people were plunged into . roaring torrent, which, but a few minutes previously, had been a ıarmless dry arroyo.

The results of floods are manifold, the most important, doubtless. ɴeing the financial losses incurred, which may amount to millions of lollars in a comparatively small area; in addition they often cause ;reat hardships, including loss of life and the suffering and sickness 'aused by exposure and privation. Some of the greater losses affect he country not only locally, but at large. Among those may be men-ioned the destruction of farms, as was the case in considerable areas ılong Kansas River after the great flood of 1903. What had been 'ertile and productive farms prior to the flood were washed, worth-ess stretches of sands after its subsidence.

The destruction of mills or of dams furnishing water power for rrigation works, bridges, etc., is a blow to the whole section of the ·ountry where they occur.

Damage to or destruction of a system of sewerage, drainage, or vater supply is very apt to injuriously affect the health of a city or ;ommunity, and it frequently happens that an epidemic follows such ın occurrence, and, finally, the effect of damage to any one of the ;taple crops is always reflected on the various markets of the world ınd may cause unsettled conditions of the business of a whole country.

PREVENTION OF FUTURE DAMAGE.

In considering this phase of the problem streams may be divided nto three classes and each class treated separately in accordance vith the natural conditions of the country.

(1) Mountainous streams, i. e., streams having their sources and heir courses mostly in a mountainous country where the percentage ɔf rainfall is large and the run-off rapid.

(2) Arid-plains streams, i. e., streams that head or flow through ın arid or semiarid plains country, where the precipitation is small, :he evaporation large, and the run-off small.

(3) Streams flowing through a comparatively level or rolling ;ountry having a humid climate, where the rate of run-off may be ɜither rapid or sluggish.

In the case of mountain streams forests generally equalize the rate ɔf run-off. In the absence of these recourse to storage must be had to ɜqualize the flow.

In the case of plains streams, where the water is needed for irrigation, the great problem is the storage of the water. Generally, however, the topography is such that it is very difficult to find reservoir sites of any considerable size.

Probably the most practical plan for the partial elimination of some of the dangers from floods in humid sections of the country would be the careful protection of the remaining forests along these streams, the reforesting of the sections of the bottom lands rendered worthless by recent floods, the enactment and enforcement of State laws regulating the erection of bridges and preventing any encroachment on the natural waterway by individuals or corporations, and the dredging and straightening of river channels where necessary.

CACHE LA POUDRE RIVER AND CROW CREEK FLOOD.[a]

PRECIPITATION.

On May 20 a very heavy local rainfall in the southwestern part of Laramie County, Wyo., and the northeastern part of Larimer County, Colo., caused North Fork of Cache la Poudre River and its tributaries and Crow and Lone Tree creeks (which join Platte River near Greeley) to be in destructive flood on the night of May 20 and the forenoon of May 21.

That the area over which heavy precipitation occurred was small can be approximately seen from the measured depth of rainfall on May 20, given in the following table, prepared from the United States Weather and Crop Service report:

Precipitation, in inches, in Colorado and Wyoming, 1904.

Place.	May 19.	May 20.	May 21.
Cheyenne, Wyo	T.	1.73	0.15
Laramie, Wyo		.15	.07
Greeley, Colo		.09	
Fort Collins, Colo	T.	.21	
Boulder, Colo		T.	.03
Alford, Colo		2.66	
Grover, Colo		.30	
Denver, Colo		T.	.01

The location of these precipitation stations and the streams in this locality can be seen from fig. 14.

[a] From reports of James A. Armstrong, irrigation engineer, and A. J. Parshall, resident hydrographer.

FLOOD ON CACHE LA POUDRE RIVER.

The storm appears to have originated in the Stonewall Mountains and range of upper foothills at the head of North Fork of Cache la Poudre River, and to have covered Dale, Lone Pine, Stonewall, and Dry creeks, and also Lone Tree and Crow creeks. It began about noon on May 20 and lasted five or six hours. A considerable portion of this country being rough, with steep slopes entirely destitute of

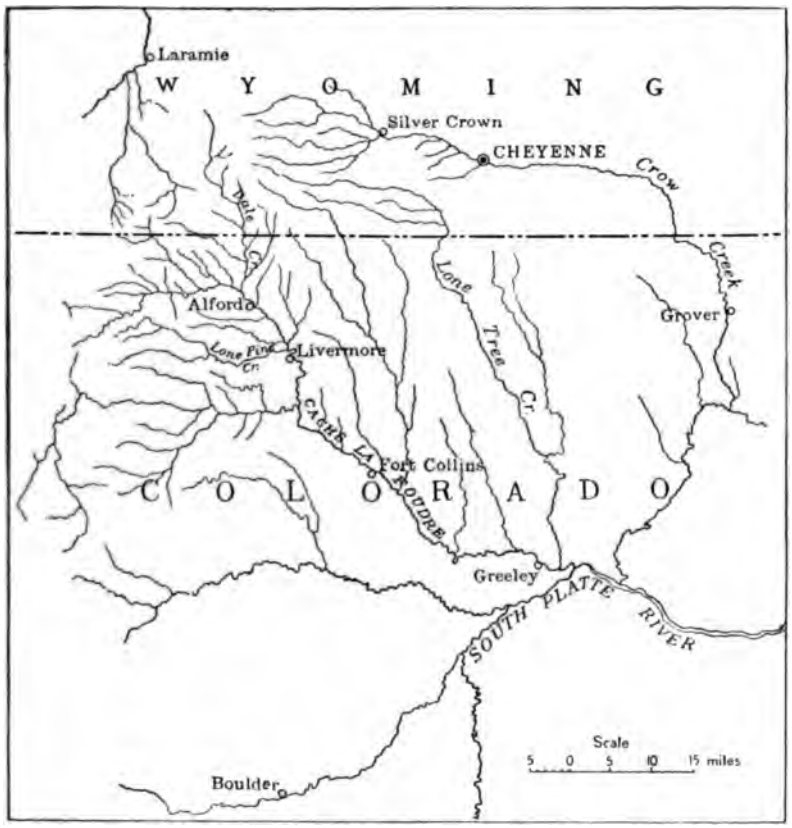


FIG. 14.—Drainage basins of Cache la Poudre River and Crow Creek.

timber, and the beds of the streams being very steep, the run-off was very rapid. Mr. Armstrong thus describes the flood on the Cache la Poudre:

The flood was down into Livermore almost before anyone could remove anything out of the way, and had it been in the night there would probably have been a great loss of life as well as of property. The flood reached the main Cache la Poudre early in the afternoon, and was augmented by floods down Dry Creek and Hook and Moore canyons, which empty into the main Cache la Poudre below the mouth of the canyon. These probably added as much more water to the already swollen stream.

The flood was at its height at Fort Collins late in the afternoon and early evening, remaining up from two and one-half to three hours. From Fort Collins to Greeley the river has less grade than in the hills and the water traveled more slowly, giving the people time to prepare, as they were warned in ample time. As the bottom lands are much wider, the flood did not reach Greeley until about 6 a. m. on the morning of May 21.

Mr. Armstrong estimates the maximum rate of discharge at Livermore at 20,000 cubic feet per second, and states that this flood was the greatest in at least thirty-four years. People living in the valley since 1859 declare that this flood was 1.5 feet higher than the great flood of 1864.

The loss in Larimer and Weld counties, Colo., consisted mainly in damage to farm property, to irrigation ditches, to roads and bridges, and to railway property. These are summarized in the following table:

Damage from Cache la Poudre flood in Colorado.

Larimer County:		
Homes and farms	$62,250	
Ditches	35,000	
Roads and bridges	50,000	
		$147,250
Weld County:		
Homes and farms	19,400	
Roads and bridges	5,000	
		24,400
Railroad bridges and tracks washed out, Colorado and Southern and Union Pacific, in both the above counties		12,000
Total loss in these two counties		183,650

FLOOD ON CROW CREEK.

The storm on Crow Creek appeared to have been greatest near the junction of South, Middle, and North forks, about 18 miles west of Cheyenne. When visited by Mr. Parshall, two days after the storm, there was no evidence of a heavy storm above this place, while below it on every side were seen torn fences and great deposits of silt and débris.

Mr. Parshall thus describes the flood at places along Crow Creek:

About 9 p. m. on May 20 the residents along Crow Creek were suddenly confronted by a wall of water several feet high extending across the valley, varying in width from one-fourth to one-third of a mile, and moving with great rapidity. The resulting damage was the loss of the lives of two children and the destruction of a considerable amount of property, viz. of railway and highway bridges, embankments, public works, and residences. The first alarm at Cheyenne was sounded from the city pump house, a substantial stone structure located near the creek in West Cheyenne, its floor being about 7 feet above the

bed of the stream and about 120 feet distant from it. At 9 p. m. May 20 the engineer and family living in the house were warned of some unusual occurrence by a roaring noise, and opening the door were almost simultaneously struck by a wave estimated to have been 3 feet high. The water continued to rise for about three-fourths of an hour, when it reached its greatest height, 5.5 feet above the floor of the building and 12.5 feet above the bed of the creek. Here the width of the bottom covered with water was nearly one-fourth of a mile. After 10 o'clock the water gradually subsided, and at daylight the following morning only a swollen stream with slimy, wreck-strewn banks was to be seen.

State Engineer Johnson was on the ground at the time and estimated the discharge of the creek at Cheyenne to vary from 7,000 to 10,000 cubic feet per second for several hours, this estimate being based on his knowledge of discharge of streams. The loss caused by the flood consisted mainly of damage to railway property, the Colorado and Southern Railway Company being without doubt the heaviest property loser. The points of greatest destruction were between the junction of the forks and Cheyenne. Immediately below the junction is the roadbed of the Colorado and Southern, lying close to the stream and largely constructed on embankments. Farther down are the filter beds of the Cheyenne city waterworks, and 15 miles from the junction the city of Cheyenne, where the creek passes under the tracks of the Union Pacific Railroad.

The bridge at Silver Crown station (13 miles west of Cheyenne) was washed out, and between that point and the city 4 or 5 miles of roadbed was washed away. The destruction was complete, scarcely one rail being left in place, and where the embankment stood the creek, when the storm had subsided, had in many places cut a new channel.

The loss to the city of Cheyenne was considerable. A portion of the dam used in connection with the filter beds was washed away, the beds covered with a mass of mud and débris, and a portion of the flume, which conveyed the water to the locks, was destroyed.

The iron bridge which spanned Crow Creek at Nineteenth street was wrecked and the wooden bridge at Fortier Park, Sixteenth and South Cheyenne streets, was entirely carried away. The Union Pacific Railroad Company lost its big pile bridge over the creek on the Denver line, and was obliged to replace a large amount of washed-out embankment near the city.

Several houses belonging to the poorer classes were carried downstream and many more were flooded with water, some having been twisted around upon the lots and greatly damaged.

The loss to the ranchmen along the stream was not as great as at first supposed, for while many fences and small buildings were destroyed and lands covered with silt, yet, generally, the silt had a

beneficial effect upon the land, and the crops later in the season showed a marked improvement over those of former years. An approximate estimate of the damage done along this creek is as follows:

Damage from Crow Creek flood, 1904.

Colorado and Southern Railway	$40,000
City of Cheyenne	15,000
Union Pacific Railroad	10,000
Individual losses	10,000
Total	75,000

PURGATORY RIVER FLOOD.[a]

The largest and by far the most destructive flood recorded in the history of Purgatory River occurred from 10 p. m. September 29 to 8 a. m. September 30, 1904. All the city bridges in Trinidad were washed away or badly damaged, the city water supply was cut off by the destruction of the main pipe line, the electric-light plant was disabled, telephone communications were cut off, and railway services were entirely abandoned. In three hours public, private, and corporate property was damaged to the extent of $350,000. No lives were lost, an almost miraculous fact considering the suddenness and magnitude of the flood and its occurrence in the night.

STREAM AND DRAINAGE BASIN.

Purgatory River rises in the Culebra Mountains in the southwestern part of Las Animas County, Colo., flows in a general northeasterly direction, and joins the Arkansas near Las Animas, Colo. The drainage basin is about 120 miles long and from 30 to 40 miles in width and comprises an area of about 3,390 square miles.

The upper and mountainous part, lying above Trinidad, has an area of 742 square miles and consists mainly of shales and sandstone, with some igneous rocks. It is carved into valleys where the formation is shale and into canyons where the formation is more resisting. The vegetation of the lower half of this area is largely cedars and bunch grass; of the upper portion pine, cedar, fir, and the usual Colorado mountain flora. Ground storage of rain in this part of the basin is small owing to the steep slopes.

The lower part, having an area of 2,640 square miles, extends from Trinidad to the mouth of the river. The soil here is largely decomposed shale, with some sand and limestones. The vegetation consists of cedars, bunch grass, cactuses, etc. Surface storage is small. This is a characteristic stream of eastern Colorado, heading in the mountains, flowing across the plains, and carrying little water except dur-

[a] By R. I. Meeker, assistant engineer.

ing floods. It is the principal southern tributary of Arkansas River. In the spring the channel carries a moderate volume of water, but as summer approaches this is gradually diminished by irrigation and

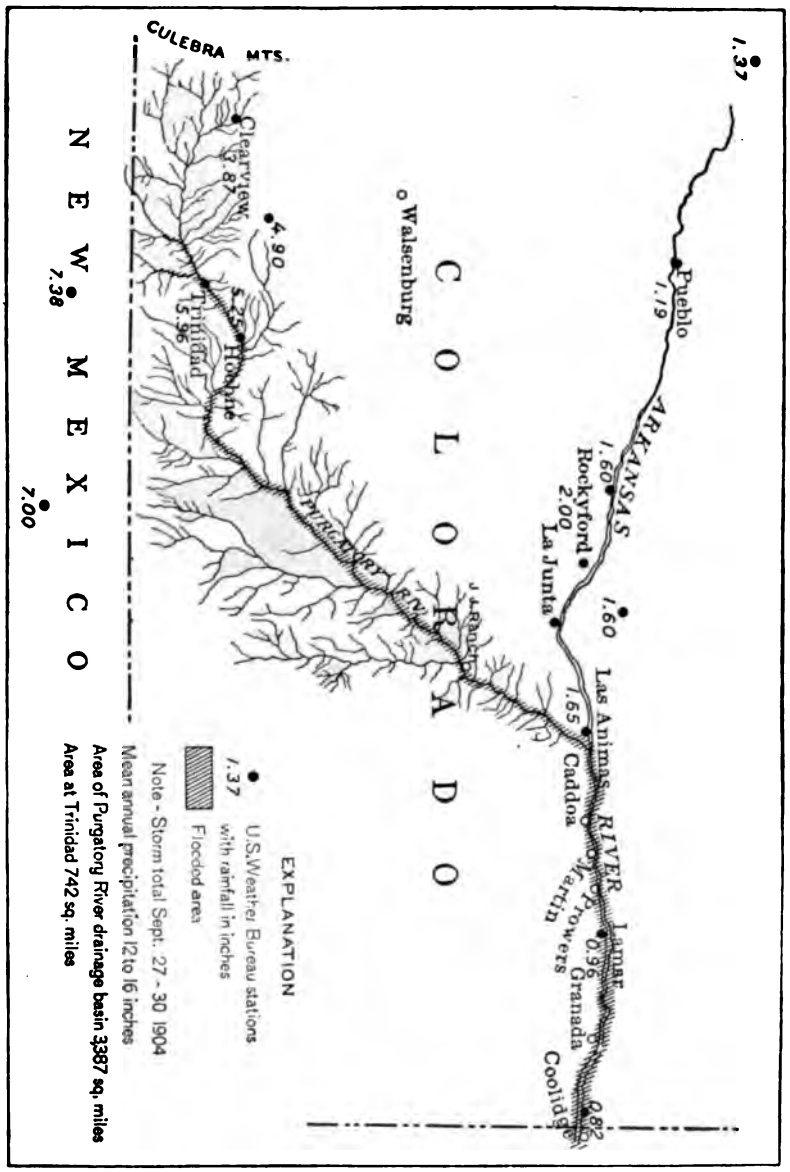


FIG. 15.—Drainage basin of Purgatory River.

natural conditions until the channel is practically dry. The volume of water contributed to the Arkansas by this stream is so small that it has scarcely an appreciable effect upon the discharge of the Arkansas, except at times of excessive local rainfall. Its flow is very

erratic; the discharge may vary from a few second-feet to several thousand in a few hours.

PRECIPITATION.

The mean annual precipitation over this drainage basin varies from about 13 inches near the mouth to about 23 inches near the source, the September average from source to mouth being from about 1 inch to 1.2 inches. The following table [a] gives the depth of rainfall for the month of September, 1904, at several places along Arkansas and Purgatory rivers:

Precipitation, in inches, in Purgatory River basin, Colorado, for September, 1904.

Day.	Santa Clara.	Fowler.	Rocky Ford.	Sugar City.	Las Animas.	Clear View.	Trinidad.	Hoehne.	Lamar.	Holly.
1	T.	0.26	0.16	0.17	0.20	.....	.....	.....	0.60	0.22
2	T.	.55	.18	.25	.10	.....	0.28	0.12	.17	.36
3	.....	.....	.....	.....	.....	0.14	.....	.....	.....	.....
9	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	0.05	.....	.....	.....	.....	T.	.....	.....	.....	.....
12	.....	.....	.....	.....	.....	.....	.....	T.	.....	.....
14	.05	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	T.	.....	.....	.....	.....	.08	.....	.....	.....	.....
18	T.	.....	.....	.....	.....	.10	.....	T.	.....	.....
19	T.	T.	T.	.07	.....	.14	T.	T.	.....	.....
20	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....
21	T.	.....	.....	.....	.....	.....	.55	.....	.....	.....
22	T.	.....	.....	.....	.....	T.	.....	.....	.....	.....
23	.....	.....	.....	.....	.....	.05	.....	.....	.....	.....
25	T.	.....	.....	.....	.....	.03	.....	.....	.....	.....
26	T.	.....	.....	T.	.....	.04	.....	.....	.....	.....
27	T.	.25	T.	T.	.....	.48	.18	.....	.11	.....
28	.75	.25	.13	.06	.....	2.03	.72	.10	.18	.28
29	1.79	1.10	1.49	1.46	1.20	1.36	1.92	3.00	.41	.32
30	2.36	T.	.38	.08	.45	.....	3.13	2.15	.26	.02
Total	5.00	2.41	2.34	2.09	1.95	4.45	6.78	5.37	2.59	2.27
Departure from the normal	+3.17	.....	+1.69	.....	+1.05	+3.46	+5.71	+4.37	+1.54	+1.00

The following table gives the daily depth of rainfall at three places in this basin from September 26 to 30, 1904:

Precipitation, in inches, preceding Purgatory River flood, 1904.

Place.	Elevation in feet.	Sept. 27.[b]	Sept. 28.	Sept. 29.	Sept. 30.	Total.
Trinidad	6,000	0.18	0.72	1.92	3.13	5.95
Hoehne	5,271	.....	.10	3.00	2.15	5.25
Clear View	9,500	.48	2.03	1.36	.....	3.87

[a] Prepared from records of United States Weather Bureau.
[b] From 5 p. m. Sept. 26 to 5 p. m. Sept. 27.

e location of the precipitation stations along Arkansas and Pur-
y rivers are shown in fig. 15 (p. 159).

September 27 a moderate rain began to fall over the upper part
e Purgatory drainage basin, continuing with increasing inten-
until the evening of September 29, when it became excessive.
o 9 p. m. on September 29, 4 inches fell at Trinidad, and from
hour to 9 a. m. September 30, 2 inches more fell. By this time
torm had grown in extent and had become general over the en-
drainage basin. It was heaviest along the southern mountain
shed of the Purgatory above and below Trinidad, and traveled
y from west to east. This movement, together with the physical
acter of the southern portion of the drainage basin, accounts for
nmense amount of water which arrived at the mouth of the Pur-
y. The rainfall of the upper tributaries reached Trinidad
st simultaneously with the greater portion of the flood, which
into the Purgatory from Long Creek, about 6 miles above
dad.

FLOOD ON PURGATORY RIVER PROPER.

ood near Trinidad.—Trinidad is located in the narrow valley
e the Purgatory leaves the mountains, the business portion of the
lying along each side of the river and the residence portion on
er ground. The slope of the bed of the river at this place is
39 to 40 feet per mile, and the sides of the valley are steep,
mainly shale, highly eroded, and cut into well-rounded quick-
channels, causing the run-off to be very rapid. Purgatory
at Trinidad was not carrying more than the usual volume of
until the evening of September 29, when the very heavy rainfall
d the river to rise very rapidly. Local information is con-
ng as to the exact cause of the large volume at Trinidad. Some
residents report a cloud-burst above the city in the river canyon,
ewhere; others maintain that the origin of the great volume was
ncreasing heavy downpour. From personal investigation Mr.
er was led to the conclusion that the great volume was due to
xcessive rainfall of a few hours, following a constant rain of
three days over an area of very rapid run-off.

Weston, 20 miles above Trinidad, the Purgatory, though high,
not overflow its banks. Between this point and Trinidad the
ne discharged into the Purgatory from southern tributaries was
tionally large. Local residents all agree that Long and Raton
ons discharged an immense volume of water on the night of Sep-
er 29. This large discharge from southern tributaries indicates
ater rainfall to the south, which is corroborated by heavy rainfall
ds in northern New Mexico.

A trustworthy eyewitness, employed at the Cardenas Hotel at Trinidad, describes the flood at this place as follows:

> The river was high on the afternoon and evening of September 29, and rose steadily during the early part of the night. At 11 p. m. the water level was still 1.5 feet below the level of the river banks and about 5 feet deep in the channel. Shortly after this time the river rose rapidly, and by 2.30 a. m. was at its highest stage, being 2 feet deep on the lawn of the Cardenas Hotel and within 5 inches of the hotel floor. This stage of the river lasted until about 4 a. m., when it began to fall. By 8 a. m. on September 30 the river was again within its banks and was rapidly receding.

At the Atchison, Topeka and Santa Fe Railway station, shown in Pl. XV, the water reached a depth of 3 feet on the platform.

In three hours $350,000 worth of property was destroyed. Of the five street bridges and two railway bridges four were swept entirely away and others were badly damaged. Several brick and stone structures adjacent to the river were destroyed. The supply main of the city water supply was carried downstream, thus disabling the service. All the railroads suffered heavily in yard tracks, bridges, and roadbeds, being completely tied up for twenty-four hours. The entire lower portion of the city was submerged for some hours, being flooded to a depth of from 1.5 to 2 feet. A large steel bridge belonging to the Colorado and Southern Railway was carried downstream 250 feet and half buried in sand and rocks. The piers were overturned and forced out of the river bed, one of them, 5 feet in diameter and concrete filled, being entirely destroyed. The city bridge at Commercial street, a steel structure on masonry piers accommodating an electric railway in addition to road and foot ways, was carried one-fourth mile downstream and reduced to a shapeless mass of twisted steel. The losses in the vicinity of Trinidad may be summarized as follows:

Losses from Purgatory River flood at Trinidad, Colo., September, 1904.

Corporation property:		
Atchison, Topeka and Santa Fe Railway	$70,000	
Colorado and Southern Railway	25,000	
Colorado and Wyoming Railway	18,000	
Denver and Rio Grande Railroad	30,000	
Other corporation property, about one-half of which was at Elmoro	17,000	
		$160,000
Public property:		
New bridges and repairs to bridges	50,000	
Straightening channel, etc	25,000	
General	25,000	
		100,000
Private property:		
Estimated		90,000
Total		350,000

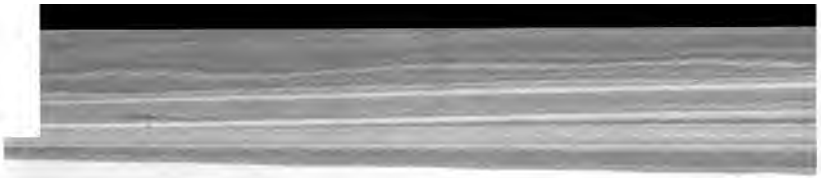
A

B

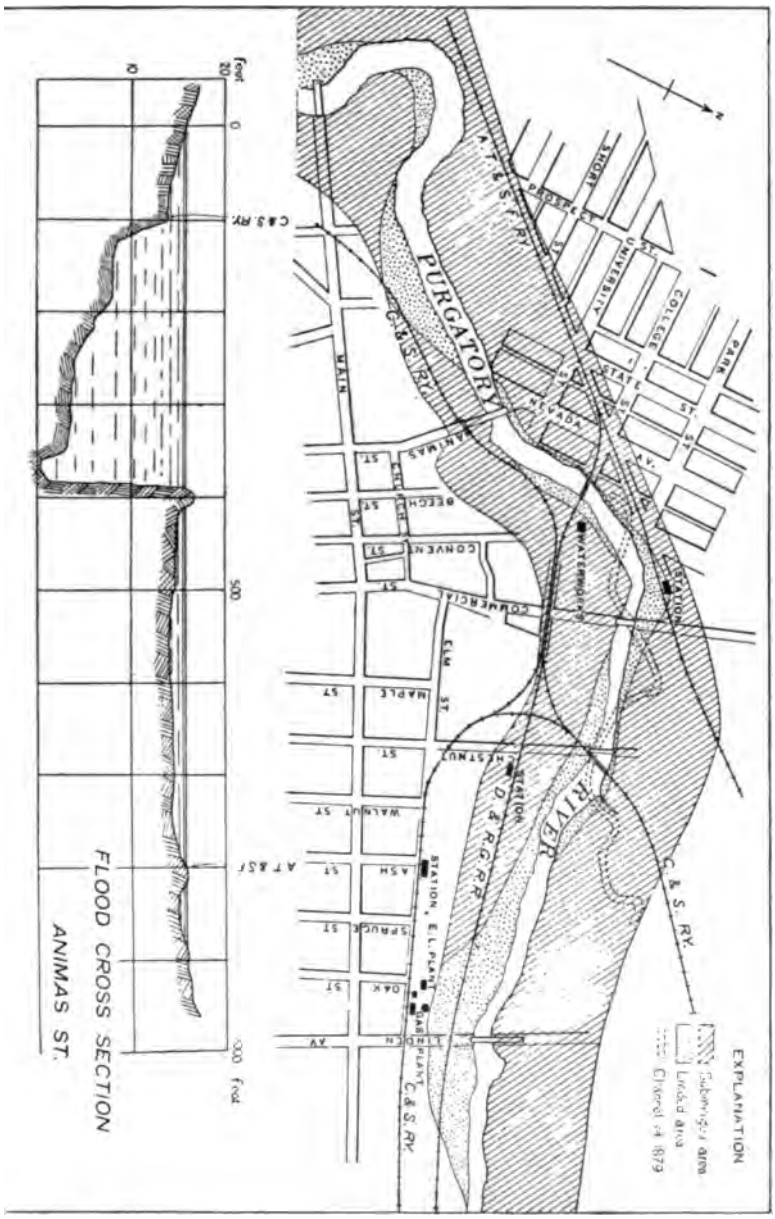
DESTRUCTION CAUSED BY FLOOD ON PURGATORY RIVER AT TRINIDAD, COLO.

A. ATCHISON, TOPEKA AND SANTA FE RAILWAY STATION AT TRINIDAD, COLO., AFTER FLOOD OF SEPTEMBER, 1904.

B VIEW SHOWING FAILURE OF DAM NEAR SCOTTDALE, PA.



ı old resident who came to Trinidad in 1862 states that at that the channel of Purgatory River was narrow, not over 30 or 40 in width, and that it has increased in width each year since that



A flood occurred at Trinidad in November, 1866, and since that there have been two large floods at this place, the exact dates volume of discharge of which could not be secured. Old resi-

dents agree that the flood of September, 1904, was considerably larger than any previous one. The changes in the channel in the vicinity of Trinidad caused by the 1904 flood are shown in Pl. XVI. The area submerged during the flood and a cross section of the stream near the Animas Street Bride are shown in fig. 16.

The maximum discharge of the river at Trinidad was computed by the use of Kutter's formula. A section was selected just below the Animas Street Bridge, where the channel is approximately straight and the change in it caused by the flood comparatively small. The bed here is composed of sand, gravel, and cobbles. The banks are mainly of earth, with a few trees, and in places it is protected with riprap or piling. The old United States Geological Survey gage on the Animas Street Bridge showed a maximum reading during this flood of 16.6 feet. The slope of the river was measured with a level for a distance of about 500 feet above and below this section and found to be about 37 feet to the mile. The area of cross section is 2,670 square feet, wetted perimeter 275 feet, hydraulic radius 9.71 feet, and the coefficient of roughness was taken as 0.035. The mean velocity was found to be 16.61 feet per second and the discharge 44,322 cubic feet per second. The estimated volume of water not included in this section, passing on the right and left banks, is 1,100 second-feet; the maximum rate of flow was, therefore, 45,422 cubic feet per second. The mean rate of flow from September 28 to October 2, inclusive, was 5,061 cubic feet per second, and the total approximate discharge 50,000 acre-feet. This result is based upon depth of water in river from September 28 to October 2, as given by local residents.

The detailed estimated discharge from September 28 to October 2, inclusive, was as follows:

Discharge, in second-feet, of Purgatory River at Trinidad, Colo., 1904.

September 28	1,400
September 29	5,594
September 30	15,585
October 1	2,000
October 2	750

On October 3 a discharge measurement was made from a temporary footbridge at Commercial street and the discharge found to be 270 cubic feet per second.

Flood below Trinidad.—From Elmoro to the mouth of Purgatory Canyon, a distance of 28 miles, the valley widens and is occupied by farms and ranches on either side for the entire distance. These ranches were injured to a considerable extent. Fences and hay were washed away, cattle and hogs drowned, and minor dam-

EROSION OF BANKS OF PURGATORY RIVER, TRINIDAD, COLO.

; sustained. The loss to farmers in implements, crops, etc., is esti-
ed at $25,000.

.ecords in the possession of the Atchison, Topeka and Santa Fe
lway Company show that previous floods required approximately
nty-four hours to pass from Trinidad to Las Animas. The flood
October, 1904, passed over this distance in from nineteen to
nty hours. Fortunately there was only a small amount of water
he Arkansas above the mouth of the Purgatory; otherwise the
d of the lower Arkansas would have been much more destructive.
Santa Fe road from Holly to Las Animas was completely tied
for seven days.

'he flood of October 1 was the greatest on record on this stream.
residents declare that it was 2 feet greater than the flood of
5.

'he following statements concerning the flood of 1875 are taken
n the Las Animas Leader of September 18 and 25, 1875:

> n September 16 a rush of water came down Purgatory River at Las Animas.
> . The water was 5 feet higher than at any previous time that year. The
> ison, Topeka and Santa Fe Railway Company's tracks were under water
> one-half mile on each side of the Purgatory, the bridge being 3 to 4 feet
> r water. At Fort Lyon the water was 4 feet higher than ever known
> re. The bottom land between the bridge and the post trader's (a distance
> hree-fourths of a mile) was a swift, raging flood. Up the Purgatory con-
> rable damage was done, the greatest losses being of cord wood, stacked
> cattle, fences, and adobe houses. The Arkansas above the mouth of the
> gatory was also in flood at this time, there being reports of damage as far up
> 'ueblo. The Apishapa brought in a large amount of this water, and the
> l height was the highest in fifteen years.

PURGATORY FLOOD ON THE ARKANSAS.

'lood in Colorado.—On the Arkansas the lower bottom lands
e entirely inundated from the mouth of Purgatory River to the
orado-Kansas State line. As a flood at this season of the year
unexpected, both the Atchison, Topeka and Santa Fe Railway
npany and the farmers were entirely unprepared for it, and
damage done was much greater than it otherwise would have
n.

'rom Fort Lyon to Holly the water covered all the lower bottom
ls, and from Caddoa to Lamar, where the bottom is narrower
n above or below, the waters reached from bluff to bluff, a distance
ying from three-fourths to 1 mile in width.

.t the Colorado and Kansas canal dam, 1 mile east of Martin, the
keeper was compelled to swim his horses out, so rapid was the
of the water.

At Powers the water was 3.5 feet deep on the level in places on each side of the Atchison, Topeka and Santa Fe Railway, and the residents were compelled to take refuge on house tops and in trees. Hogs, bees, poultry, and cattle in large numbers were drowned, and thousands of tons of alfalfa were destroyed by the water, which reached an average height of 3 feet on the stacks. The Amity canal dam, which is just below Powers, was damaged by the flood to the extent of $20,000; the apron was practically off the dam at the time, and the terrific force of the current, augumented by the contracted river channel, had free access to the foundations, completely sweeping the dam away between crib No. 1 on the north and pier No. 2, a distance of 165 feet.

At Lamar, where the river channel is at the north of the town, the river was about 1½ miles in width. If it had risen another foot the town of Lamar would have been flooded. The damage in this vicinity was largely to alfalfa seed hay, which was stacked in the bottoms ready for thrashing, and to other forage and cattle.

The Salvation Army colony at Amity, located in a bottom level with the river, suffered more severely than any other settlement in the valley. The entire settlement was inundated and the total damage heavy.

Farther east the damage was small, as the river channel is a large shifting bed of sand, and the ranches are scattered and well back from the river.

All bridges over the Arkansas from the mouth of the Purgatory to Coolidge, Kans., inclusive, were badly damaged except the steel structure at Granada. The tracks of the Santa Fe, which parallel Arkansas River, were badly damaged. At the east end of the La Animas-Santa Fe Railway Bridge across the Purgatory the flood cut away 400 feet of roadbed and earth bank, which was protected with stone riprap work placed on grillage. The overflow from the river channel carried 2½ miles of rail and ties off the embankment and badly damaged 2 additional miles of roadbed, cutting out the ballasting and the underlying embankment, although the track remained in place. This damage from overflow began a little west of Caddoa and extended to a point about 1 mile east of Powers, the greatest damage being done in the vicinity of Martin.

The Atchison, Topeka and Santa Fe Railway bridge across the Arkansas a short distance east of Byron was so badly damaged that about two-thirds of it had to be rebuilt.

The losses in Arkansas Valley in Colorado are estimated as follows:

Damage by flood in Arkansas Valley, in Colorado, 1904.

Public property:		
Repairs to bridges and roads from mouth of Purgatory to Colorado-Kansas line estimated at		$50,000
Private property:		
Damages to meadow lands, fences, hay, cattle, etc		100,000
Corporation property:		
Atchison, Topeka and Santa Fe Railway	$75,000	
Dam and canals in valley	25,000	
		100,000
Total		250,000

There is a gaging station on Arkansas River, about 5 miles upstream from Powers, Colo., and about 1 mile east of Martin, at the dam used to divert the water of the Arkansas into the Colorado and Kansas Canal. During the flood the water reached a height of about 8.3 feet on its crest. An earth dike extending about 500 feet from its north end was washed away by the flood and about 185 feet of the crest so injured that its elevation on the left side was about 0.22 foot lower than before the flood. High-water marks of this flood were secured from lines on north and south abutments which were not entirely submerged. At the south abutment the flood reached 8.15 feet above the crest; on the north abutment, 8.9 feet. The greater height was probably due to the fact that the main current was near this end of the dam. On account of the irregularities in the crest of the dam, 8.3 feet is considered the maximum height of the flood. Mr. W. H. Houston, gate keeper, reports that the river began to rise about 12 o'clock midnight, continuing gradually until a. m., at which time the water reached the floor of his house. The maximum stage was reached about 9 a. m. and lasted about one hour. The river then began to recede and at 3 p. m. the gage registered 4 feet.

The flood at this place reached from bluff to bluff, a distance of about 4,500 feet. It is difficult to calculate the discharge at this section on account of the large area of overflow and its varying slope and roughness of bed. The maximum discharge of the flood, computed by Kutter's formula, was found to be from 65,000 to 75,000 cubic feet per second; of this volume about 38,000 cubic feet passed over the dam and from 27,000 to 37,000 cubic feet on either side. In the computations of the volume of water passing around the dam the average slope of the river bed in this vicinity was assumed to be slightly less than that of the river channel, 0.001 being used. The coefficient of roughness n varied from 0.030 to 0.040.

The gage height at this station during the flood and the corresponding discharge over the dam are as follows:

Gage height and discharge on Arkansas River at Colorado and Kansas Canal dam, September 29 to October 4, 1904.

Date.	Height in feet.			Discharge in cubic feet per second.
	6 a. m.	6 p. m.	Mean.	
September 29	0.20	0.20	0.20	.....
September 30	1.30	2.50	1.90	5,800
October 1	7.50	4.00	5.75	23,700
October 2	2.50	2.00	2.25	7,200
October 3	1.90	1.80	1.85	5,600
October 4	1.00	.80	.90	1,700
Total				44,000
Average				8,800

The discharge of the streams from September 30 to October 4, inclusive, as computed from the above gage heights, was 87,296 acre-feet passing over the dam and 22,000 acre-feet passing around the dam; total, 109,300 acre-feet.

The increase of flow at this place to twice that at Trinidad was due to the water from the drainage of southern tributaries entering below Trinidad, large volumes entering from Rule, Caddoa, and Muddy creeks. There was practically no storage of any of this water.

Flood in Kansas.—The flood, as it moved down Arkansas River, was gradually absorbed by the sandy bed and banks, being thus considerably reduced in volume and destructiveness. The highway bridges at Hartland, Lincoln, Ingalls, Garden, Dodge, and Kinsley were damaged, short sections of these bridges in most cases being carried out. Very little damage was done to crops along the river, as it did not overflow in cultivated portions of the valley.

The following table gives the mean daily gage height and corresponding discharge of the river at Syracuse, Dodge, Hutchinson, and Arkansas City during this flood, also the total volume of this flood at these places:

eight and discharge of Arkansas River in Kansas, October 1 to 15, 1904.

e.	Syracuse.		Dodge City.		Hutchinson.		Arkansas City.	
	Mean gage height in feet.	Discharge in second-feet.	Mean gage height in feet.	Discharge in second-feet.	Mean gage height in feet.	Discharge in second-feet.	Mean gage height in feet.	Discharge in second-feet.
r 1	6.75	18,690						
r 2	7.00	21,300	6.75	15,010				
r 3	5.70	10,610	6.25	13,175	3.20	2,500		
r 4	4.70	4,575	4.50	7,125	4.80	8,000		
r 5	3.80	1,250	3.90	5,085	3.90	4,425		
r 6	3.70	1,075	3.40	3,625	4.30	5,965	7.30	5,400
r 7	3.70	1,075	2.85	2,220	3.90	4,425	6.90	4,590
r 8	3.50	785	2.40	1,325	3.65	3,695	6.50	3,850
r 9	3.50	785	2.25	1,120	3.50	3,275	6.20	3,350
r 10	3.50	785	2.20	1,050	3.25	2,625	5.80	2,725
r 11			2.10	910	3.30	2,750	5.30	2,075
r 12					2.60	1,300	5.10	1,835
r 13							4.90	1,610
r 14							4.60	1,300
r 15							4.40	1,125
tal		60,930		50,645		38,960		27,860
low for 10 days		6,093		5,064		3,896		2,786
eet for 10 days		120,824		100,419		77,258		55,246

the 120,824 acre-feet that passed Syracuse, Kans., only 55,246 eet reached the southern border of Kansas at Arkansas City. more than half the entire flood volume was absorbed in its ge through Kansas.

nage.—The total damage caused by the flood in Colorado and is will approximate closely $650,000.

LA PLATA RIVER FLOOD, COLORADO.[a]

October 6, 1904, a storm occurred on La Plata River, a tribu- of the San Juan, that caused the greatest flood along the middle ower part of this valley since 1882. This stream and the storm are shown in fig. 17. In the vicinity of the mouth of the La the storm began at about 1 p. m. October 6, traveling very rap- up Jewett Valley through the "Meadows," reaching Navajo gs at 1.15 p. m. and La Plata and Pendleton at 1.30 p. m., in-

[a] Prepared from report of Mr. Theo. Tobish, field assistant.

creasing in fury as it went north. At Pendleton from 1.30 to 3 p. m. the storm was at its height, the rain coming down in very heavy gusts at intervals of about ten minutes, and at 2 o'clock and thereafter accompanied by heavy hailstones, which accumulated at various places to a depth of 8 inches. During those two hours the precipitation was about 1 inch.

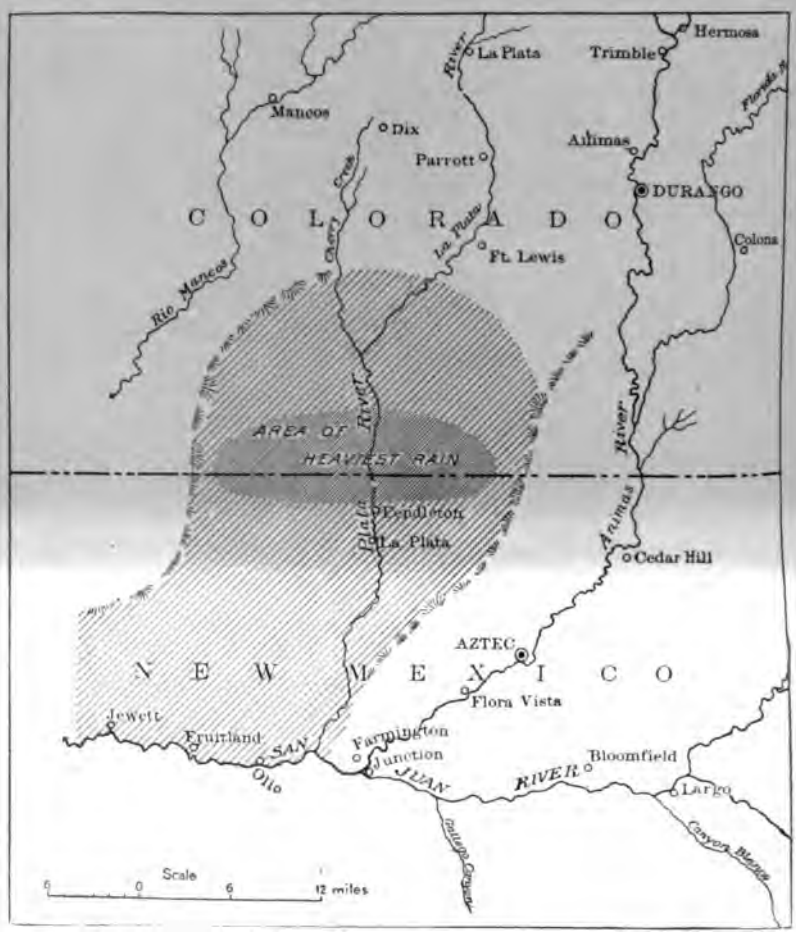


FIG. 17.—Drainage basin of La Plata River and area of heaviest rainfall on October 8, 1904.

The heavy slope of the valley, combined with a large amount of run-off, caused the river to begin to rise very rapidly at 3 p. m. It continued to rise and fall several feet in half an hour, as the canyons above discharged their water. At 4 p. m. it had reached its maximum stage at Pendleton, passing over the floor of the highway bridge at a depth of 2 feet. At 5 o'clock the rain ceased except for a light

izzle, and the river fell very rapidly until 7 p. m., when another avy shower fed the river and in about fifteen minutes caused it to e to the approaches of the bridge. This shower continued for out two hours, when it moderated and settled into a steady rain it lasted until 4 o'clock the following morning. On Friday, Octo- 7, there were no heavy rains, but a light drizzle fell until the ning, when another shower occurred lasting about four hours. this time the fury of the storm had spent itself, although in some alities in the northern part of the valley there were unimportant ht rains on October 8.

The river remained at an extremely high stage for two hours, and s at flood stage for thirty-six hours after the beginning of the rm.

The maximum discharge of this stream near Pendleton was com- ted by Mr. Tobish from Kutter's formula. The natural width of channel at this place is about 30 feet, but the water overflowed banks and had a width of 265 feet. The bed proper is composed bowlders and stone, but the overflow portion of the section is ckly covered with willows. The slope was found to be 0.0052, the a 1,176, and wetted perimeter 280. From these data and the lue of $n=0.040$, the mean velocity was found to be 7 feet per ond and the maximum discharge 8,232 cubic feet per second. e discharge was also measured at three other places along the eam, but the channel conditions were so unsatisfactory that the ults were not considered reliable.

Much damage was done in various ways by the storm, the hail troying the fruit crop, which was nearly ready for market, and flood damaging to a considerable extent the reservoirs and irriga- n ditches. It is claimed by some, however, that the benefits ived from the irrigation of the farms along the river will nearly set the damage done to the fruit. The estimated damage in the ley to orchards, crops, and alfalfa seed is about $7,500.

The greatest damage done by the storm was to the reservoirs and igation ditches, all the former, excepting the Johnson and Conger ervoirs, being destroyed. This destruction of the reservoirs is ieved to have been due almost entirely to faulty construction, the ndation for the reservoir walls not having been properly prepared l the walls themselves not having been properly constructed, the th being merely dumped in place without being wetted or packed. other cause of failure was the fact that little or no attention had n given to the proper size of the spillways.

Sixteen irrigating ditches, having lengths varying from 1 to 7 les, were damaged by amounts varying from $50 to $750 each, the al estimated damage to ditches alone being $2,850.

FLOODS DUE TO FAILURE OF DAMS AND RESERVOIR WALLS.

By E. C. Murphy.

GENERAL STATEMENT.

Floods of this character during the past year have been quite numerous, but the only one that can be described in this paper is the failure of an earth dam near Scottdale, Pa. Description or mention of failure of other similar structures during the year may be found in engineering journals.[a]

SCOTTDALE FLOOD.

The Scottdale Valley flood, which occurred July 7, 1904, was due to the failure of an earth dam situated on Jacobs Creek, a few miles above Scottdale, Pa. This creek rises in western Pennsylvania, flows southwest and west a distance of about 25 miles, and empties into Youghiogheny River about 18 miles southeast of McKeesport, Pa.

The dam was 70 feet high, had a top width of 12 feet, a puddle core, and both faces paved with stone. It was built in 1901 and was owned by the Citizens' Water Company and used to form a reservoir to supply Scottdale and neighboring places with water. The dam failed, as shown in Pl. XV, *B* (p. 162), by the washing out of a V-shaped piece at the right end. This piece was about 100 feet wide at the top and 15 feet wide near the base. The water did not overflow the bank—in fact, it was several feet below the crest of the dam at the time of failure. A leak was noticed a considerable time before the break occurred, but efforts to stop it were unavailing. It increased until a well-defined break was discovered near the base of the dam. Failure immediately followed, liberating about 2,000,000 gallons of water. The loss caused was small on account of the sparsely settled condition of the valley, consisting mainly in damage to machinery in the pump house just below the dam, the washing away of several small bridges along the stream, and some damage to a few buildings along the creek.

The failure of this dam was due to leakage between the end of the dam and the rock side of the valley. This rock was of a shaly nature, the seams dipping 5° to 6° downstream. The earth probably settled, leaving a crack between itself and the rock. This explanation appears quite plausible from the fact that on September 14, when the writer visited the dam, there was a leak under it near the left bank that was passing more water than the natural flow of the stream. The water thus leaking under the dam was being

[a] For Winston, N. C., reservoir failure see Eng. News, vol. 53, 1904, p. 444.

mped back into the reservoir. An attempt had been made to stop .s leak by a cut-off wall, but it had apparently resulted in failure. ıe upstream face of several hundred feet of the part of the dam ıt did not completely fail slipped down toward the water, a dis- ıce of from 1 to 3 feet, leaving cracks of from 1 to 4 inches in dth.

The dam was immediately rebuilt, and precaution was taken to event the water from passing around the end of the dam by build- g a masonry wall into the rock of the hillside and extending it t into the core of the dam. It is quite evident that a sufficient ıount of care was not taken in constructing the dam to prevent .kage underneath and around the ends.

DROUGHT IN OHIO RIVER DRAINAGE BASIN.

By E. C. Murphy.

INTRODUCTION.

The severe drought of 1904 in the Ohio drainage basin and in the uthern and New England States calls attention to the fact that not ly in the arid West may there be a shortage of rainfall, and conse- ently of water supply, but that such conditions may occur east of e Mississippi also, and brings prominently to view the necessity for undant storage of flood waters. Fortunately the 1904 drought came ar the end of the growing season and did not cause a severe short- e of crops, though it seriously affected manufacturing, railway, and vigation interests in the Ohio drainage basin.

The normal monthly distribution of rainfall over the United States ries greatly. On the Pacific coast the winter months are wet, the ımmer months are dry; on the Great Plains the reverse is true—the ımmers are comparatively wet and the winters dry. East of the ssissippi the precipitation during the winter months is generally out the same as during the summer months, but there are great riations from the normal rainfall. The areas of low and high ecipitation are frequently comparatively small. In a few hours' le on the train one will often see a marked change in the vegetation, e to the amount of moisture in the soil, this being especially true the Great Plains region. Short periods of diminished rainfall are mmon east of the Mississippi; west of the Mississippi they are more equent and of longer duration.

STREAMS AND DRAINAGE BASIN.

The drainage basin of the Ohio (see Pl. XVII) is the second in ze of those forming the great Mississippi drainage basin. It has a ngth of about 660 miles, a width of 480 miles, and an area of about

the Tennessee, Cumberland, Kentucky, Big San
Kanawha, and Monongahela. North of the Ohio
of gently rolling cultivated land, with little timb
ern portion of the basin, which is mountainous an
south of the Ohio. The Wabash, Miami, Scioto,
the principal tributaries from the northern part

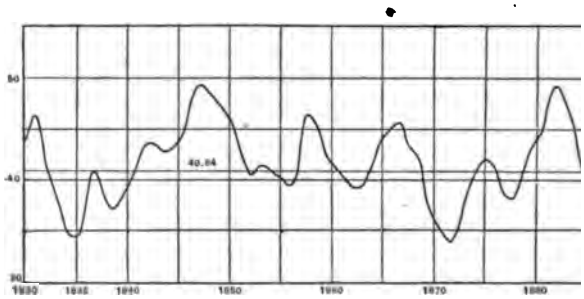
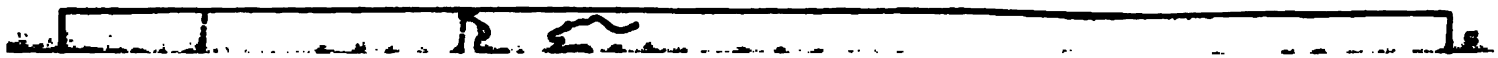


FIG. 18.—Curve showing mean annual precipitation at three drainage basin from 1830 to 1904.

flow is very different in character from the southe
less rapid and more nearly uniform.

PRECIPITATION.

The annual precipitation over the basin may b
about 35 to 45 inches. The mean of the ann
Marietta, Portsmouth, and Cincinnati from 18
in fig. 18, in which the curve shows the variat
from year to year. The years 1835, 1871, 18



long the Ohio are usually referred to the low water of 1895. It will be interesting to compare the precipitation and stream stages from 1893 to 1896 with those from 1899 to 1904 for places north of the Ohio and also south of or on it. The places selected for this comparison and the annual precipitation at each for these periods are given below.

Annual precipitation, in inches, at places in Ohio River drainage basin.

Place.	1893.	1894.	1895.	1896.	1900.	1901.	1902.	1903.	1904.
Oil City, Pa	49.97	34.32	40.81	40.97	37.83	47.49	45.54	48.90	41.71
Dayton, Ohio	38.93	26.79	25.89	32.25	33.86	26.05	35.97	38.69	37.19
Terre Haute, Ind	39.61	29.12	32.50	37.27	30.47	31.78	34.88	33.22	39.27
Mean	42.84	30.08	33.07	36.83	37.05	35.11	38.80	40.27	39.39
Mean	35.70				38.12				
Confluence, Pa	43.30	42.14	35.11	50.22	44.03	41.17	45.92	37.12	31.38
Charleston, W. Va	41.10	32.73	32.26	44.72	40.20	45.94	45.37	38.40	.....
Salmouth, Ky	41.45	26.30	29.84	39.59	40.53	29.82	40.76	37.46	32.33
Cincinnati, Ohio	44.00	26.59	29.33	34.48	27.78	17.99	37.30	34.69	29.54
Louisville, Ky	43.93	38.08	38.86	48.22	38.04	29.53	41.65	33.69	29.25
Mean	42.77	33.17	33.08	43.45	38.12	32.89	42.20	36.27	30.62
Mean	42.80	32.01	33.75	40.97	37.72	33.72	40.92	37.77	34.38
Mean	37.21				36.90				

It appears from this table that the mean precipitation for the period 1893–1896 for these eight places is 0.3 inch greater than for the period 1899–1904.

The mean of the three places north of the river is 1.51 inches less than the mean for the five places south of or on it for the first period (1893–1896) and 1.22 inches greater than for the second period—that is, the drought was more severe north of the Ohio from 1893 to 1896 than south of it, and the opposite for the period 1899 to 1904.

The table below gives the monthly precipitation at each of these eight places and the monthly variation from the normal at some of them for two years of the first period and three years of the second period.

Monthly precipitation, in inches, and variation from normal at places in Ohio River drainage basin.

OIL CITY, PA.

[P., precipitation; V., variation from normal.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	3.48	2.94	1.90	3.17	5.04	1.62	1.95	0.41	6.51	2.43	2.22	2.65	34.32
1895 (P.)	4.63	1.49	1.64	2.68	4.22	2.58	3.65	3.09	5.15	1.24	5.11	5.32	40.80
1901 (P.)	2.55	1.76	4.34	5.99	5.14	5.37	3.42	4.11	6.61	6.39	3.96	4.31	47.95
1903 (P.)	3.82	5.07	5.06	3.44	2.62	7.08	7.04	4.32	2.04	2.92	2.67	2.82	48.90
1903 (V.)	+ .58	+1.79	+1.81	+ .67	-1.31	+2.32	+2.49	+1.42	-1.65	+ .38	- .89	- .42	+ 7.19
1904 (P.)	5.45	3.51	6.10	4.50	4.30	2.30	3.42	4.02	2.66	1.64	.92	2.80	41.71

Monthly precipitation, in inches, and variation from normal, etc.—Continued.

DAYTON, OHIO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	2.33	3.79	2.57	1.67	3.90	2.05	0.42	2.63	1.53	0.90	1.81	3.19	28.79
1895 (P.)	4.08	.18	1.35	1.80	1.51	3.43	.74	2.25	.66	.80	5.93	3.16	25.89
1901 (P.)	2.00	1.33	2.42	1.87	3.45	4.04	1.33	.91	2.32	1.12	1.43	3.83	26.05
1901 (V.)	−1.06	−1.86	− .85	−1.06	− .39	+1.08	−1.59	−2.03	− .38	− .91	−1.96	+1.32	−[illegible]
1903 (P.)	2.39	4.79	3.69	3.66	4.66	9.09	1.43	1.17	.65	2.72	2.44	2.00	38.[illegible]
1903 (V.)	− .67	+1.60	+ .42	+ .86	+ .03	+4.83	−1.46	−1.56	−1.95	+ .48	− .79	− .64	+1.[illegible]
1904 (P.)	4.61	2.53	7.90	3.18	4.05	2.47	3.04	1.87	2.00	1.23	.63	3.68	37.[illegible]
1904 (V.)	+1.55	− .66	+4.63	+ .38	+ .32	−1.79	+ .15	− .86	− .60	−1.01	−2.60	+1.0[illegible]	+ .[illegible]

TERRE HAUTE, IND.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	1.99	2.73	2.10	2.11	3.63	2.56	3.04	3.63	1.94	0.87	1.30	3.22	29.12
1895 (P.)	2.26	.38	1.64	4.37	.85	2.75	4.20	4.96	2.09	.63	4.58	3.79	32.50
1901 (P.)	1.16	1.59	4.39	2.98	2.47	6.51	.46	2.63	.42	3.06	1.93	4.18	31.78
1903 (P.)	2.32	3.67	2.72	4.35	3.20	2.24	2.15	3.38	2.94	3.31	1.15	1.79	33.22
1903 (V.)	+ .02	+1.64	−1.57	+1.11	+ .14	−2.58	− .84	+ .52	+ .12	+1.06	−2.08	− .86	− 3.32
1904 (P.)	4.59	1.32	8.94	5.00	4.41	1.91	2.75	2.32	3.74	.81	.29	3.19	39.27
1904 (V.)	+1.56	− .93	+4.19	.....	+1.24	−2.58	− .24	.....	+ .92	−1.44	−2.94	+ .54	.....

CONFLUENCE, PA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	3.15	3.57	2.36	4.94	5.86	2.90	3.00	1.37	3.48	2.71	2.87	5.93	42.74
1895 (P.)	2.98	1.43	4.03	3.57	1.94	4.28	6.18	3.75	.68	.67	3.02	2.58	35.11
1901 (P.)	2.91	1.25	4.35	5.86	6.32	1.99	3.55	4.07	2.49	.85	2.88	4.65	41.17
1903 (P.)	4.46	1.98	2.93	3.00	3.16	3.74	5.90	3.22	1.64	2.64	2.91	1.54	37.12
1903 (V.)	+ .63	−1.79	−1.05	− .44	− .96	− .50	+ .67	− .29	−1.48	− .22	− .49	−1.99	− 7.91
1904 (P.)	2.87	2.66	4.18	3.20	4.03	1.62	2.34	4.08	1.20	1.53	.43	3.24	31.38

CHARLESTON, W. VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	2.35	4.57	1.94	3.06	3.52	2.86	0.66	2.05	3.77	1.65	2.39	3.91	32.73
1895 (P.)	5.19	.69	3.87	2.60	2.08	1.83	4.19	4.81	1.05	.72	2.54	2.69	32.26
1901 (P.)	2.10	.32	3.36	6.85	5.40	6.92	2.08	5.00	3.57	.70	2.23	7.41	45.94
1903 (P.)	2.52	6.36	4.56	5.95	1.83	4.21	2.76	1.93	.57	3.43	2.16	2.12	38.40
1903 (V.)	−1.07	+2.83	+ .22	+2.54	−2.20	− .58	−1.03	−2.69	−1.89	+1.51	−1.21	−1.28	− 4.65
1904 (P.)	1.68	2.63	3.54	4.08	2.72	2.69	3.28	3.45	.....	1.65	.45	2.61	.....

FALMOUTH, KY.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894 (P.)	2.92	3.09	2.50	3.20	3.03	1.62	0.74	1.88	1.46	1.47	0.72	3.67	26.30
1895 (P.)	5.62	.58	1.73	2.70	2.18	2.46	4.06	1.13	.49	.84	3.34	4.71	29.84
1901 (P.)	1.01	1.68	2.60	3.67	3.03	3.68	2.34	2.74	2.02	.84	1.46	4.75	29.82
1903 (P.)	2.47	7.25	3.47	4.35	2.22	2.78	2.65	4.36	1.30	2.20	2.04	2.37	37.[illegible]
1903 (V.)	−1.28	+3.81	− .34	+1.06	−1.27	−1.31	−1.04	+1.24	− .64	− .03	−1.08	− .60	−2.[illegible]
1904 (P.)	2.88	2.63	1.62	3.00	1.92	3.96	0.96	2.20	1.69	.67	.75	4.05	32.33
1904 (V.)	− .82	.....	+3.58	.....	−1.37	− .13	−2.55	.....	− .24	−1.47	−3.06	.....	.....

[a] Approximate.

onthly precipitation, in inches, and departure from normal, etc.—Continued.

CINCINNATI, OHIO.

Date.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
4 (P.)	2.75	3.78	2.36	1.60	2.33	4.17	0.13	1.98	2.48	0.82	0.98	3.23	26.59
5 (P.)	6.13	.37	1.51	2.62	1.82	2.15	2.27	3.29	.49	73	4.66	3.29	29.33
1 (P.)	.87	1.35	2.01	1.93	1.62	2.27	1.44	.88	.92	59	.74	3.37	17.99
1 (V.)	−2.51	−2.17	−1.60	− .95	−1.70	−1.69	−2.05	−2.66	−1.43	−1.68	−2.59	+ .41	−20.52
8 (P.)	2.05	5.76	4.97	3.49	3.83	3.27	2.31	2.75	1.78	1.31	1.45	1.72	34.69
8 (V.)	−1.4	+2.1	+1.7	+ .3	+ .4	−1.1	−1.1	−1.0	− .6	1.1	−1.8	−1.4	− 5.18
4 (P.)	2.66	2.66	8.17	2.28	3.70	2.60	.80	.41	1.28	.89	.34	3.75	29.54
4 (V.)	− .8	−1.2	+4.9	− .9	+ .3	−1.8	−2.6	−3.3	−1.14	−1.55	−2.96	+ .63	−10.5

LOUISVILLE, KY.

4 (P.)	2.81	5.09	3.04	3.98	3.90	3.63	2.41	3.57	2.64	K20	0.63	5.18	38.08
5 (P.)	4.54	.64	2.10	3.10	2.88	4.94	5.68	1.35	.41	.90	7.01	5.31	38.86
1 (P.)	.98	1.16	3.59	2.49	2.45	4.12	2.85	2.86	2.78	.49	1.17	4.59	29.53
8 (P.)	2.43	6.08	3.18	4.82	2.23	3.52	1.25	3.51	.83	1.60	2.71	1.58	33.69
8 (V.)	−1.6	+1.7	− .8	+ 4	−1.5	− .8	2.5	.0	−2.00	−1.2	−1.4	−2.3	−12.07
4 (P.)	2.43	3.54	6.49	2.67	1.77	1.71	1.70	2.11	2.65	.27	.25	3.66	29.25
4 (V.)	−1.6	−1.0	+2.5	−1.8	−2.0	−2.6	−2.1	−1.4	− .17	−2.54	−3.81	− .2	−16.8

From this table it appears that the smallest monthly precipitation ı the first period was 0.4 inch and in the second period 0.25 inch—ıat is, there was one-fourth inch or more rainfall per month : each of these places during both these dry periods. There is seen ı be an annual deficiency at Cincinnati of 20.52 inches in 1901, deficiency of 10.2 inches in 1904, and an accumulated deficiency rom 1901 to 1904 of 39.7 inches. The deficiency at Louisville was 2.1 inches in 1903 and 16.8 inches in 1904.

RUN-OFF AND DISCHARGE.

As a result of the large deficiency in the precipitation over this rainage basin, especially south of the Ohio, the flow of the streams ecame very small, causing great inconvenience and loss to navigation nd other interests along the river. The following table gives the luctuations of the surface of Ohio River at Wheeling, Portsmouth, nd Louisville from August to December, 1895 to 1904, as shown by he United States Weather Bureau gages at these places. The greatst, the least, and mean gage height for each month is given at each of hese places.

Gage height, in feet, in places along the Ohio, August to December, 1895 to 1904.

Place.	Year.	August.			September.			October.		
		From—	To—	Mean.	From—	To—	Mean.	From—	To—	Mean.
Wheeling, W. Va.	1895	3.5	1.2	2.4	3.3	1.7	2.3	1.9	0.6	1.2
	1904	5.1	1.6	3.1	3.4	1.3	2.2	4.9	2.6	3.2
Portsmouth, Ohio.	1895	6.0	3.6	4.5	4.1	2.5	3.3	2.9	1.3	1.7
	1904	6.3	3.6	4.8	5.3	2.1	3.3	3.6	1.9	2.8
Louisville, Ky.	1895	6.4	3.2	4.2	4.2	3.0	3.5	3.4	1.8	2.5
	1904	4.0	3.5	3.7	4.0	2.5	3.1	2.8	2.0	2.5

Place.	Year.	November.			December.		
		From—	To—	Mean.	From—	To—	Mean.
Wheeling, W. Va.	1895	8.7	0.8	2.9	16.5	2.9	6.3
	1904	3.9	1.3	2.2	[a] 16.0	1.4	3.8
Portsmouth, Ohio	1895	4.0	1.3	2.3	22.8	3.1	8.8
	1904	4.3	2.4	2.9	[b] 17.5	2.2	3.8
Louisville, Ky	1895	4.1	1.8	2.3	9.0	3.0	5.0
	1904	3.1	2.2	2.6	3.4	2.2	2.6

[a] Began to rise December 25 from 2.5 feet. [b] Began to rise December 27 from 2.7 feet.

At Wheeling the range of stage in 1895 was from 0.6 to 3.5, except for a few days in December; in 1904 it was from 1.3 to 5.1, except for a few days in December. It is thus seen that while the mean stage for the five months was less in 1904 than in 1895, the stream at this place reached a lower stage in 1895 than in 1904.

The mean stage at Portsmouth for the five months is also less in 1904 than in 1895, but the lowest for any month was in 1895. The same is true of the stages at Louisville.

A stage of 0.6 foot at Wheeling means a depth on bars from Davis Island dam to Wheeling of from 6 to 20 inches. Hence from the latter part of July to near the end of December, 1895, and also for the same period of 1904, boats could not pass from Pittsburg to Wheeling.

The United States Geological Survey has upward of 30 gaging stations in this drainage basin, and the intensity of the drought can be seen from the records at these stations. The location of these gaging stations on the more important streams is shown in Pl. XVII (p. 174). In order to economize space, the principal results are presented in two tables.

The table on page 179 gives the run-off per square mile in cubic feet per second at 20 of these stations for each month from June to December; also the mean for the seven months. The area of each

of these basins above the point of measurement is given in the table on page 181, and the volume passing each station per month can easily be computed. South of Ohio River the minimum flow occurred in October; north of the Ohio it occurred at some time between September and November. The smallest monthly flow of any of these streams was that of Scioto River at Columbus, being 0.029 second-foot per square mile in September.

Run-off per square mile, in second-feet, of streams in Ohio drainage basin, June to December, 1904.

Stream and place.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Licking River, Pleasant Valley, Ohio	0.721	1.310	0.197	0.130	0.154	0.145	0.398	0.437
Wabash River, Logansport, Ind	1.940	.845	.128	.139	.124	.110	.345	.519
Tippecanoe River, Delphi, Ind	.634	.660	.282	.318	.310	.236	.....	.406
Olentangy River, Columbus, Ohio	.360	1.220	.041	.053	.045	.038	.198	.294
Scioto River, Columbus, Ohio	.231	1.380	.048	.029	.042	.046	.105	.269
Mahoning River, Youngstown, Ohio	1.76	.324	.246	.073	.049	.084	.238	.396
White (East Branch) River, Shoals, Ind	.485	.314	.132	.107	.089	.073	.190	.199
Youghiogheny River, Friendsville, Md	1.19	0.627	.183	.153	.207	.168	2.72	.747
New River:								
Radford, Va	1.49	1.03	1.08	.520	.299	.492	.576	.784
Fayette, W. Va	1.34	.828	.604	.274	.173	.239	.427	.555
Greenbrier River, Alderson, W. Va	.988	.262	.105	.064	.045	.062	.307	.262
French Broad River, Oldtown, Tenn	1.13	.748	1.08	.648	.303	.543	.792	.749
Tennessee River, Knoxville, Tenn	.725	.678	.703	.362	.219	.317	.702	.529
Pigeon River, Newport, Tenn	.997	.913	.890	.519	.281	.420	.808	.690
Nolichucky River, Greenville, Tenn	1.19	.847	.921	.521	.336	.535	.791	.734
South Fork Holston River, Bluff City, Tenn	.664	.622	.699	.331	.223	.351	.786	.525
Little Tennessee River, Judson, N. C	1.47	1.07	1.60	.951	.444	.699	1.43	1.095
Tuckasegee River, Bryson, N. C	1.42	1.12	1.39	.885	.579	.690	1.22	1.043
Hiwassee River:								
Murphy, N. C	1.30	.927	1.40	.688	.429	.546	1.07	.909
Reliance, Tenn	.991	.788	1.08	.530	.349	.476	1.09	.758

The table below gives more detailed information of the flow at gaging stations in this basin for the five months July 20 to December 20. Column 4 of this table gives the maximum daily rate of flow and column 5 the minimum daily rate during the five months at these stations. Column 6 gives the dates of beginning and ending of the period of six or more days when the discharge was least; column 7 gives the number of days of this period, and column 8 the discharge during that time. It frequently happens that a dam on the stream holds back the water for a few days, so that the smallest daily flow may be much less than the average flow for a week or more when the flow is least. A comparison of the corresponding numbers in columns 5 and 8 will give a good idea of the minimum flow, and also of the average for a week or longer when the flow was least.

Data on minimum flow of streams in Ohio drainage basin, 1904.

[Discharge in cubic feet per second.]

Name of river.	Place.	Drainage area in square miles.	Daily discharge, July 20 to December 20.		Period and amount of least discharge.		
			Maximum.	Minimum.	Date.	Days.	Discharge for period in second-feet.
Licking	Pleasant Valley, Ohio.	696	810	66	Nov. 27-Dec. 5	9	66
Olentangy	Columbus, Ohio	520	104	5	Sept. 26-Oct. 4	9	5
Scioto	do	1,051	215	7	Sept. 24-Sept. 29	6	24
Mahoning	Youngstown, Ohio.	958	985	[a] 0	Oct. 1-Oct. 10	10	[b] 23
Wabash	Logansport, Ind.	3,163	1,118	280	Oct. 18-Nov. 13	26	350
Tippecanoe	Delphi, Ind	1,890	1,200	291	Aug. 7-Aug. 16	10	335
White	Shoals, Ind	4,900	1,330	215	Oct. 22-Dec. 23	63	300
Allegheny	Kittanning, Pa	8,690			Sept. 19-Sept. 26	8	2,000
Kiskiminetas	Salina, Pa	1,769			Sept. 24-Oct. 6	13	175
Blacklick [c]	Blacklick, Pa	403			Aug. 30-Sept. 8	10	45
Youghiogheny	Confluence, Pa	392			Oct. 1-Oct. 8	8	35
Castleman	do	482			Sept. 22-Oct. 13	22	44
Laurel Hill [c]	do	126			Oct. 14-Dec. 14	62	16
New	Radford, Va	2,725	14,905	690	Oct. 13-Oct. 25	13	690
Do	Fayette, W. Va	6,200	6,216	984	Oct. 6-Oct. 13	8	1,050
Greenbrier	Alderson, W. Va	1,344	217	46	Sept. 30-Oct. 6	7	46
Cumberland	Nashville, Tenn		4,630	1,000	Sept. 24-Oct. 2	9	1,100
Tennessee	Knoxville, Tenn	8,900	13,710	1,750	Oct. 15-Nov. 3	20	1,930
Do	Chattanooga, Tenn				Oct. 21-Nov. 2	13	4,980
French Broad	Oldtown, Tenn	1,737	2,955	400	Oct. 4-Nov. 2	29	535
Pigeon	Newport, Tenn	655	1,660	160	Oct. 11-Nov. 2	23	180
Nolichucky	Greenville, Tenn	1,099	2,043	320	Oct. 13-Oct. 27	15	355
Little Tennessee	Judson, N. C	675	3,280	275	Oct. 13-Nov. 1	20	275
Tuckasegee	Bryson, N. C	662	3,050	340	Oct. 28-Nov. 2	6	340
South Fork Holston.	Bluff City, Tenn	828	1,140	150	Oct. 9-Nov. 3	26	190
Hiwassee	Murphy, N. C	410	3,230	150	do	26	190
Do	Reliance, Tenn	1,180	3,780	380	Oct. 19-Oct. 26	8	380

[a] Affected by dam. [b] Average for ten days. [c] Creek.

It will be seen that the streams south of the Ohio not only have a larger minimum flow per square mile of drainage area, but their flow fluctuates less rapidly than those north of the river.

SOME EFFECTS OF THE DROUGHT.

The drought had a serious effect on the navigation interests of the Ohio. Boatmen declare that it was the worst in their recollection. For seven months navigation was practically suspended from Wheeling to Pittsburg. It is estimated that 13,000,000 bushels of coal were tied up at points along the Ohio and tributaries waiting for a rise in the river to take them down to Cairo. The South was suffering for the coal that was held along the river and the miners were working on half time on account of lack of facilities for transporting the coal to the consumers. (See Pl. XVIII.)

The great steel and iron industries in western Pennsylvania and Ohio suffered directly from lack of suitable water for boilers and indirectly for lack of fuel, the railroads not being able to haul the fuel for lack of water for boiler purposes. The Edgar Thompson Company shut down part of its steel plant for lack of water. The furnaces had no coke and the boilers had badly corroded from the sulphur in the water which came from the mines. The National Tube Works and the Duquesne and Homestead mills could not run to their full capacity. Many of the coke ovens suspended operations and the loss in the coke region was estimated at $1,000,000 per month.

The oil industries suffered for lack of water and in many cases this scarcity caused suspension for a time. Where it was possible in the oil fields water was hauled for the boilers from considerable distances.

The railroads suffered to a large extent. Many of the streams from which their local supplies were taken became dry and it was necessary to haul the water for the engines in some cases from a long distance. The writer counted 12 tank cars of water in a train on the Baltimore and Ohio that was on its way from Grafton to Clarksburg and other watering stations. The Pennsylvania Railroad and other roads in this basin were compelled to haul water for their engines to various points. The water was not only scarce but very poor in quality, containing so much sulphur as to render it almost unfit for boiler use.

Many farmers suffered inconvenience and loss from lack of water for stock and household purposes. Springs, wells, and streams of considerable size in West Virginia and Kentucky were dry and farmers were compelled to haul water from a considerable distance.

The water supply of several towns in western Pennsylvania, West Virginia, and Kentucky was almost exhausted and property was without adequate fire protection for a time. The water company which supplies Braddock, Pa., announced in December that it

could not guarantee a supply of water. The Westmoreland Water Company, which supplies Greensburg, Jeannette, Manor, and Irwin, Pa., with water, stated on December 21 that there was only sufficient for a week's supply. Many towns found it necessary to curtail the use of water for bathing purposes.

The remedy for this lack of water during droughts is to store an abundant supply of flood water. Fortunately the mountainous region of West Virginia, Pennsylvania, and Kentucky affords many sites for the storage of moderately large volumes of water at a reasonable cost. Already many of these towns in this region have such storage supplies, and this drought will undoubtedly stimulate the construction of other storage reservoirs for the supply of cities and towns and also industrial organizations.

A METHOD OF COMPUTING CROSS-SECTION AREA OF WATERWAYS.

By E. C. Murphy.

The proper size of channel cross section of a stream depends mainly on the rate of flow of the stream. The method proposed in this paper for finding cross-section area is based on the fundamental formula that $F=\frac{Q}{V}$, where F is the cross-section area of the stream, Q the maximum discharge in cubic feet per second, and V is the velocity of the maximum discharge in the channel.

The formulæ in common use for this purpose generally have the form $F = CM^k$, in which F is the cross-section area in square feet, M is the drainage area in square miles or acres, C is a quantity whose value depends on the character of the country, and k is a fraction generally less than unity; e. g., the formula used by the engineers of the Missouri Pacific Railway Company is $F = 0.25\ M$ to $0.17\ M$. The proposed method is based on measurements of the flood flow of streams and on the observed maximum range of stage and slope of each particular stream.

FACTORS DETERMINING MAXIMUM DISCHARGE.

The maximum discharge of a stream depends on several quantities. Primarily it is dependent on—

(1) Extent, duration, and intensity of precipitation, especially the latter in the case of small drainage basins.

(2) Direction of motion of the storm causing the flood. If the storm moves in the direction of flow of the stream the intensity of flood will be greater than if it moves in the opposite direction or across it.

BIG SANDY RIVER, NEAR MOUTH, SHOWING EXTREME LOW-WATER CONDITIONS IN NOVEMBER, 1904.

(3) The amount of snow on the ground and the temperature during the storm. Large floods are often due largely to melting snow when the ground is frozen, and in such cases the run-off is much larger than the rainfall.

(4) The storage, both natural and artificial, in the drainage basin. Storage spreads the flood over a larger period and thus reduces the maximum rate of flow.

(5) The size of the drainage basin. Rain storms of great intensity generally cover a comparatively small area, and a larger part of a small drainage basin is more likely to be covered by a very intense storm than of a larger basin. The maximum discharge per square mile will, therefore, increase as the size of the drainage basin decreases.

(6) The physiography of the drainage basin. The maximum rate of flow from a comparatively long and narrow drainage basin, with tributaries entering a considerable distance apart, will be less than from a basin of nearly circular shape of the same size, but with the tributaries entering the main stream in close proximity. Steep, impervious, deforested slopes of drainage basin, steep slope of bed of tributaries, and small slope of main stream intensify flood flow.

Among the more or less artificial conditions that increase the flow may be mentioned controlled storage in the basin; deforestation and cultivation; reduction in width of channel by placing abutments of bridges in the stream; the use of piers that prevent scour of bed, collect drift, and hold back a part of the flow for a time, causing a greatly increased flood wave; the formation of ice gorges; and the failure of dams and reservoir walls.

Freshets occur on all streams, usually once a year, sometimes two or more times a year; great floods that result from natural causes occur at irregular intervals, varying from a few years to many years apart. It is impossible to predict the time of their occurrence or determine whether the largest recorded flood is the largest that will ever occur.

It is very difficult to measure the discharge of a stream at maximum stage with accuracy. At such a time the stream usually carries much drift, overflows its banks, and changes its stage rapidly, all of which make accurate measurement of flow difficult.

MAXIMUM RATE OF DISCHARGE.

It may be seen, from the foregoing and other facts that might be cited, that the rate of flood discharge of streams in different drainage basins will differ by a considerable amount. The difficulty of measuring the rate of flow of any flood and the uncertainty whether any flood will be the greatest that will ever occur on that stream are both

so great that it is useless to attempt to figure closely the maximum rate of flow. It will suffice, therefore, to divide the country into six or eight parts, according to the topography and rainfall, and to obtain a relation between rate of flow and size of drainage basin for each. The tables below give the maximum rate of flow per square mile from drainage basins in various parts of the United States, the drainage area in square miles above the point of measurement, and the date of flood. It is impossible to give, except in a very few cases, the duration of the maximum rate of flow. In some cases the duration was probably not more than half an hour; in other cases the maximum rate given is the mean for several hours, and possibly for twenty-four hours of the day when the flow was greatest. It is assumed that the maximum rate given is for a period of less than twenty-four hours, unless otherwise stated.

These data are selected from a large mass of flood-flow records and are the largest rates of flow that appear to be fairly reliable that the author has seen. Some of these were obtained from careful weir measurements, while others are rough estimates.

Maximum rate of discharge of streams in northeastern United States.

[In second-feet per square mile.]

Stream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
Budlong Creek, Utica, N. Y	1.13	Mar. 25, 1904	120.40	U. S. Geol. Sur. W. S. P. No. 147.
Sylvan Glen Creek, New Hartford, N. Y.	1.18	do	56.58	Do.
Pequest River, Hunts Pond, N. J.	1.70		25.30	N. J. Geol. Sur., 1894, pt. 4.
Starch Factory Creek, New Hartford, N. Y.	3.40	Mar. 25, 1904	109.62	U. S. Geol. Sur. W. S. P. No. 147.
Reels Creek, Deerfield, N. Y.	4.40	Mar. 26, 1904	48.36	Do.
Skinner Creek, Mannsville, N. Y.	6.40	— —, 1891	124.20	U. S. B. Engrs. D. W., 1899.
Coldspring Brook, Mass	6.43	Feb. —, 1886	48.40	Trans. Am. Soc. C. E., vol. 25.
Croton River, South Branch, N. Y.	7.80	— —, 1869	73.90	Trans. Am. Soc. C. E., vol. 4.
Woodhull Reservoir, Herkimer, N. Y.	9.40	— —, 1869	77.80	Do.
Stony Brook, Boston, Mass	12.7		121.00	Report of Stony Brook Flood Com.
Great River, Westfield, Mass	14.0		a 71.40	Report of H. F. Mills.
Smartswood Lake, N. J	16.0		68.00	N. J. Geol. Sur., 1894, pt. 4.
Williamstown River, Williamstown, Mass.	16.5		34.00	U. S. B. Engrs. D. W., 1899.
Croton River, West Branch, N. Y.	20.5	Jan. —, 1874	54.40	E. M. Treman.
Beaverdam Creek, Altmar, N. Y.	20.7		111.00	U. S. B. Engrs. D. W., 1899.
Trout Brook, Centerville, N. Y.	23.0		50.60	Do.
Wantuppa Lake, Fall River, Mass.	28.5	— —, 1875	72.00	Trans. Am. Soc. C. E., vol. 4.
Pequest River, Huntsville, N. J.	31.4		19.30	N. J. Geol. Sur., 1894, pt. 3.
Sawkill, near mouth, N. J	35.0		228.60	U. S. Geol. Sur. W. S. P. No. 35.

a Average flow for day of maximum discharge.

um rate of discharge of streams in northeastern United States—Cont'd.

ream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
ny River, Whippany,	37.0	Oct. , 1903	61.62	U. S. Geol. Sur. (unpublished).
ta Creek, Johnstown,	40.0	— —, 1896	72.40	U. S. B. Engrs. D. W., 1899.
anada Creek, Motts N. Y.	47.5	.....	34.10	Do.
t Creek, New York N. Y.	51.5	.....	53.40	Do.
ay River, Dover, N. J.	52.5	.....	43.00	N. J. Geol. Sur., 1894.
Creek, Kenwood, N. Y.	59.0	— —, 1890	41.20	U. S. B. Engrs. D. W., 1899
er, R. I.	61.0	Mar. —, 1843	120.00	Trans. Am. Soc. C. E., vol. 4.
Creek, Camden, N. Y.	61.4	June , 1889	24.10	U. S. B. Engrs. D. W., 1899.
ile Creek, Stittville,	62.6	Aug. —, 1898	124.90	Do.
kon Creek, Philadel- a.	64.6	— —, 1898	43.50	U. S. Geol. Sur., 20 An., pt. 4.
reek, Allendale, N. Y.	68.4	— —, 1891	87.70	U. S. B. Engrs. D. W., 1899.
eek, Washington, D. C.	77.5	.....	126.30	Tech. Quar. Mass. Inst., 1891.
River, Farmington,	78.0	— —, 1897	41.38	Ch. engr. water dept. N. Y. City.
ck River, Pompton,	78.0	Mar. —, 1902	55.78	U. S. Geol. Sur. (unpublished).
m River, Conn.	79.0	.....	78.10	Ch. U. S. Engr. Corps, 1878.
River, Mass.	84.5	— —, 1850	71.04	Trans. Am. Soc. C. E vol. 4.
dence Creek, Cran- . Y.	93.2	Apr. —, 1869	66.50	Black River Water Claims, vol. 1. (unpublished).
River, Chatham, N. J.	100	Oct. 11, 1903	17.20	U. S. Geol. Sur (unpublished).
er, Deer River N. Y.	101	Apr. —, 1869	78.10	U. S. B. Engrs. D. W 1899.
e River, N. J.	101	Sept. —, 1882	66.00	N. J. Geol. Sur 1894.
n Creek, Mount Pleas- t.	102	— —, 1885	112.50	Rept. Phila. water board.
ek, East Branch, Point N. Y.	104	— —, 1897	80.50	U. S. B. Engrs. D. W., 1899.
River, Mass.	109	— —, 1848	104.53	Trans. Am. Soc. C. E., vol. 4.
reek, North Branch, , N. Y.	110	— —, 1897	67.30	U. S. B. Engrs. D. W., 1899.
River, North Branch,	118	.....	51.80	Ch. U. S. Engr. Corps, 1878.
River, Mahwah, N. J.	118	Oct. —, 1903	105.09	U. S. Geol. Sur. (unpublished).
ay River, Boonton,	125	Mar. 2, 1902	22.24	Do.
t River, Laurel, Md.	137	— —, 1897	31.20	U. S. Geol. Sur., 19 An., pt. 4.
ny Creek, below Pa.	139	—, 1894	97.60	Eng. News, May, 1893.
Creek, Colemans,	141	, 1888	55.80	U. S. B. Engrs. D. W., 1899.
Creek, Oriskany,	144	Mar. 25, 1904	29.00	U. S. Geol. Sur. W. S. P. No. 147
en Creek, Frederick,	152	— , 1889	69.20	Rept. Phila. water board.
River, Ridge Mills,	153	.....	46.40	U. S. B. Engrs. D. W., 1899.
River, State dam, N. Y.	158	Mar. 26, 1904	27.34	U. S. Geol. Sur. W. S. P. No. 147.
River, Pompton, N. J.	160	, 1882	56.10	N. J. Geol. Sur., 1894.
ek, West Branch, Me- lsville, N. Y.	187	, 1885	32.70	U. S. B. Engrs. D. W., 1899.
River, Altmar, N. Y.	221	.....	27.60	Do.
ver, Forestport, N. Y.	268	.....	39.00	Do.
River, Croton dam,	339	.....	74.90	Trans. Am. Soc. C. E., vol. 4.

Maximum rate of discharge of streams in northeastern United States—Cont'd.

Stream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
Great River, Westfield, Mass.	350	.....	a151.40	H. F. Mills.
East Canada Creek, Dolgeville, N. Y.	356	Aug. —, 1898	24.70	U. S. B. Engrs. D. W., 1899.
Moose River, Ayers mill, N. Y.	407	.....	31.00	Black River Water Claims Com., vol. 1.
Stony Creek, Johnstown, Pa.	418	.....	70.00	J. J. R. Croes.
West Canada Creek, Middleville, N. Y.	518	Aug. —, 1898	24.90	U. S. B. Engrs. D. W., 1899.
Farmington River, Conn.	584	.....	41.70	Ch. U. S. Engr. Corps, 158.
Monocacy River, Frederick, Md.	665	— —, 1898	29.80	U. S. Geol. Sur., 20 An.
Passaic River, Little Falls, N. J.	773	Sept. —, 1882	24.20	N. J. Geol. Sur. 1894, pt. 3.
North River, Port Republic, Va.	804	— —, 1896	29.80	U. S. Geol. Sur., 20 An.
Passaic River, Dundee, N. J.	823	Oct. 10, 1903	43.38	U. S. Geol. Sur. W. S. P. No. 92.
North River, Glasgow, Va.	831	— —, 1896	44.80	U. S. Geol. Sur., 20 An.
Raritan River, Boundbrook, N. J.	879	— —, 1882	59.30	N. J. Geol. Sur., 1894, pt. 3.
Potomac, North Branch, Cumberland, Md.	891	— —, 1897	22.80	U. S. Geol. Sur., 19 An.
Black River, Lyons Falls, N. Y.	897	Apr. —, 1869	46.00	U. S. B. Engrs. D. W., 1899.
Schoharie Creek, Fort Hunter, N. Y.	948	— —, 1892	44.00	Do.
Genesee River, Mount Morris, N. Y.	1,070	1894–1896	39.20	U. S. Geol. Sur., 20 An.
Mohawk River, Little Falls, N. Y.	1,306	Mar. 2, 1902	21.83	U. S. Geol. Sur. W. S. P. No. 147.
Greenbrier River, Alderson, W. Va.	1,344	— —, 1897	41.60	U. S. Geol. Sur., 19 An.
Black River, Carthage, N. Y.	1,812	Apr. —, 1869	21.20	U. S. B. Engrs. D. W., 1899.
Schuylkill River, Fairmount, Pa.	1,915	— —, 1898	12.20	U. S. Geol. Sur., 20 An.
Chemung River, Elmira, N. Y.	2,055	June —, 1889	67.10	Rept. of F. Collingswood to city, 1889.
James River, Buchanan, Va.	2,058	—, 1896	15.60	U. S. Geol. Sur., 19 An.
Androscoggin River, Rumford, Me.	2,320	—, 1869	25.00	U. S. Geol. Sur., 20 An.
Genesee River, Rochester, N. Y.	2,365	Mar. —, 1865	17.00	U. S. B. Engrs. D. W., 1899.
Hudson River, Fort Edward, N. Y.	2,825	Apr. —, 1900	15.60	Rept. E. A. Bond, State engr. 1900.
Shenandoah River, Millville, W. Va.	2,995	— —, 1898	11.40	U. S. Geol. Sur., 19 An.
Mohawk River, Rexford, N. Y.	3,384	— —, 1892	23.10	U. S. B. Engrs. D. W., 1899.
Merrimac River, Lowell, Mass.	4,065	—, —	19.80	N. J. Geol. Sur., 1894, pt. 3.
Kennebec River, Waterville, Me.	4,410	—, 1896	25.20	U. S. Geol. Sur., 19 An.
Susquehanna, West Branch, Williamsport, Pa.	4,500	.....	11.60	Eng. News, Feb. 14, 1891.
Hudson River, Mechanicsville, N. Y.	4,500	—, 1869	15.50	U. S. Geol. Sur., 19 An.
Merrimac River, Lawrence, Mass.	4,553	.....	23.40	Do.
Potomac River, Dam No. 5, Md.	4,640	.....	22.20	N. J. Geol. Sur., 1894, pt. 4.
Delaware River, Lambertville, N. J.	6,500	.....	53.80	Trans. Am. Soc. C. E., vol. 1.
Delaware River, N. J.	6,750	.....	50.00	Do.
Delaware River, Stockton, N. J.	6,790	—, 1841	37.50	N. J. Geol. Sur., 1894, pt. 3.
Susquehanna River, Northumberland, Pa.	6,800	—, 1889	17.50	Eng. News, Feb. 14, 1891.

a Average flow for day of maximum discharge.

rate of discharge of streams in northeastern United States—Cont'd.

am and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
t River, Holyoke,	8,660	May —, 1854	21.10	Ch. U. S. Engr. Corps, 1878.
iver, Point of Rocks,	9,654	— —, 1897	19.40	U. S. Geol. Sur., 19 An.
t River, Hartford,	10,234	.....	20.30	Trans. Am. Soc. C. E., vol. 7.
iver, Md	11,043	.....	42.60	Eng. News, May 25, 1893.
River, Great Falls,	11,427	— —, 1889	41.20	U. S. Geol. Sur., 14 An.
iver, Chain Bridge,	11,545	— —, 1893	17.20	Do.
na River, Harris-	24,030	— , 1894	18.90	U. S. Geol. Sur., 18 An.

imum rate of discharge of streams in southeastern United States.

[In second-feet per square mile.]

am and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
ee River, Carters,	532	May 21, 1901	31.86	U. S. Geol. Sur. W. S. P. No. 75.
ver, Canton, Ga	604	Jan. —, 1895	31.50	U. S. Geol. Sur., 18 An.
e River, Bryson,	662	Mar. 19, 1899	58.23	U. S. Geol. Sur., 21 An.
nessee River, Jud-	675	Dec. 29, 1901	85.24	U. S. Geol. Sur. W. S. P. No. 75.
er, Carlton, Ga.....	762	Feb. 2, 1902	38.22	U. S. Geol. Sur. W. S. P. No. 83.
er, Waterloo, S. C..	1,056	June 8, 1903	18.00	U. S. Geol. Sur. W. S. P. No. 98.
iver, Catawba, N. C.	1,535	May 29, 1901	53.10	U. S. Geol. Sur. W. S. P. No. 75.
chee River, Oak-	1,560	Feb. 27, 1899	27.92	U. S. Geol. Sur., 21 An.
River, Macon, Ga.	2,425	Mar. 1, 1902	20.97	U. S. Geol. Sur. W. S. P. No. 83.
ver, Salisbury, N. C.	3,399	Mar. —, 1899	31.60	U. S. Geol. Sur., 21 An.
River, Milstead,	3,840	Dec. 30, 1901	18.23	U. S. Geol. Sur. W. S. P. No. 75.
r, Rome, Ga	4,001	Dec. 31, 1901	16.04	Do.
er, Alston, S. C.....	4,609	May 23, 1901	28.44	Do.
rrior River, Tusca- a.	4,900	Apr. 18, 1900	27.89	U. S. Geol. Sur., 22 An.
, Fayette, W. Va....	6,200	Mar. 4, 1899	17.83	Do.
er, Riverside, Ala...	6,859	Oct. 8, 1898	10.53	U. S. Geol. Sur., 20 An.
River, Augusta, Ga	7,294	Sept. —, 1888	a 42.50	U. S. Geol. Sur., 14 An.
River, Chattanooga,	21,418	Apr. , 1896	20.80	U. S. Geol. Sur., 19 An.

Maximum rate of discharge of streams in central United States.

[In second-feet per square mile.]

Stream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
Des Plaines River, Riverside, Ill.	630	June —, 1892	[a] 9.05	U. S. Geol. Sur., 20 An.
Verdigris River, Liberty, Kans.	3,067	July 8, 1904	16.43	U. S. Geol. Sur. W. S. P. No. 16.
Neosho River, Iola, Kans	3,670	July 10, 1904	20.33	Do.
Grand River, Grand Rapids, Mich.	4,900	Mar. 27, 1904	[a] 8.04	Do.
Smoky Hill River, Ellsworth, Kans.	7,980	May 29, 1903	[a] 1.43	U. S. Geol. Sur. W. S. P. No. 96.
Kanawha River, Charleston, W. Va.	8,900	Aug. —, 1875	13.50	Eng. News, May 25, 1893.
Blue River, Manhattan, Kans.	9,490	May 31, 1903	[a] 7.25	U. S. Geol. Sur. W. S. P. No. 96.
Republican River, Junction, Kans.	25,837	do	[a] 1.80	Do.
Mississippi River, St. Paul, Minn.	36,085	Apr. —, 1897	19.70	U. S. Geol. Sur., 19 An.
Kansas River, Lecompton, Kans.	58,550	May 31, 1903	3.98	U. S. Geol. Sur. W. S. P. No. 96.

[a] Average flow for day of maximum discharge.

Maximum rate of discharge of streams in southwestern United States.

[In second-feet per square mile.]

Stream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
Gallinas River, Las Vegas, N. Mex.	90	Sept. 30, 1904	129.10	U. S. Geol. Sur. W. S. P. No. 147.
Mora River, La Cueva, N. Mex.	159	Sept. 29, 1904	139.70	Do.
Cherry Creek, Colo.	175		57.00	U. S. Geol. Sur. W. S. P. No. 81.
Rapid Creek, Rapid, S. Dak	320	June 6, 1904	2.85	U. S. Geol. Sur. W. S. P. No. 147.
Salt Creek, at mouth, N. Mex.	3,052	Oct. —, 1904	4.10	Do.
Hondo River reservoir, N. Mex	1,387	do	4.56	Do.
Canadian River, Logan, N. Mex	11,440	do	[a] 12.29	Do.
Canadian River, Taylor, N. Mex	2,832	do	[b] 32.11	Do.
Canadian River, French, N. Mex.	1,478	do	[c] 105.56	Do.
Pecos River, Fort Sumner, N. Mex.	6,191	do	7.29	Do.
Pecos River, Roswell, N. Mex.	14,840	do	3.75	Do.
Redwater River, Belle Fourche, S. Dak.	1,006	June 5, 1904	8.00	Do.
Sapello River, Los Alamos, N. Mex.	221	Sept. —, 1904	36.7	Do.
Purgatory River, Trinidad, Colo.	742	Sept. 30, 1904	61.2	Do.
Salt River, Roosevelt, Ariz	5,756	Mar. —, 1893	36.0	U. S. Geol. Sur. W. S. P. No. 73.
Verde River, McDowell, Ariz.	6,000	do	[d] 24.05	Do.
Salt River, Ariz	12,000	Feb. —, 1891	24.69	U. S. Geol. Sur. W. S. P. No. 81.
Gila River, Florence, Ariz	17,750	Feb. 17, 1891	7.50	Do.
Pecos River, Santa Rosa, N. Mex.	2,649	Sept. 30, 1904	17.56	U. S. Geol. Sur. W. S. P. No. 147.
Mora River, Weber, N. Mex.	422	do	65.70	Do.
Rio Grande, Rio Grande, N. Mex.	11,250	Oct. —, 1904	2.75	Do.

[a] Rate for 12 hours. [b] Rate for 7 hours. [c] Rate for 0.5 hour. [d] Rate for 24 hours.

Maximum rate of discharge of streams in California.

[In second-feet per square mile.]

Stream and place.	Drainage area, in square miles.	Date.	Maximum rate.	Authority.
ion Canyon, Los Angeles,	15.5	.....	48.5	U. S. Geol. Sur. W. S. P. No. 81.
River, Bowman dam,	19	.....	31.6	Do.
twater River, Sweetwa- dam, Cal.	186	Jan. —, 1895	97.5	Do.
imne River, Lagrange,	1,501	.....	30.6	Do.
oaquin River, Hampton- e, Cal.	1,637	Jan. —, 1881	[a] 36.51	Do.
River, State Point, Cal...	1,742	Jan. —, 1901	[a] 25.22	Do.
River, Rio Bravo, Cal....	2,345	May —, 1897	[a] 2.3	Do.
mento River, Iron Can- , Cal.	9,295	Feb. —, 1904	23.47	U. S. Geol. Sur. W. S. P. No. 147.
River, Smartsville, Cal..	1,229	.....do.....	[a] 49.02	Do.
er River, Oroville, Cal...	3,350	.....do.....	[a] 31.49	Do.
Creek, Fruto, Cal	760	Mar. —, 1904	[a] 29.21	Do.

[a] Mean for day when discharge was a maximum.

ORMULAS FOR MAXIMUM DISCHARGE AND AREA OF CROSS SECTION.

ome of the data for streams in the northeastern United States plotted in fig. 19, using the areas of drainage basin in square miles bscissæ and the maximum rates of flow as ordinates. The curve , whose equation is

$$q=\frac{46,790}{M+320}+15,$$

been drawn to represent the relation between rate of flow and size rainage basin for this section of the country. In this equation, M e drainage area in square miles and q the maximum discharge in ic feet per second per square mile of drainage.

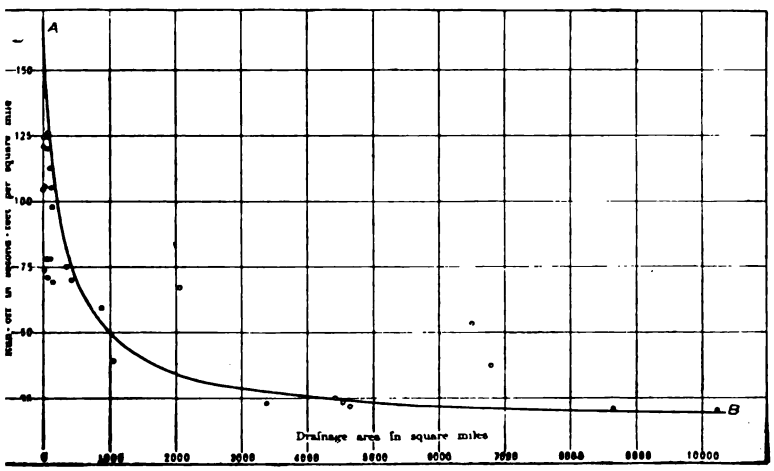


FIG. 19.—Curve showing relation between size of drainage basin and run-off per square mile.

The following table has been prepared from this equation and gives the maximum rate of flow per square mile from drainage basins of various sizes in the northeastern part of the United States. Knowing the size of the drainage basin at a given place on a stream in this section of the country, the maximum discharge is found by multiplying the drainage area in square miles by the proper value found in this table.

Values of q, the maximum rate of flow of streams, in terms of M, the drainage area in square miles, in

$$q=\frac{46,790}{M+320}+15$$

Value of M.	Corresponding value of q.	Value of M.	Corresponding value of q.	Value of M.	Corresponding value of q.
1	161	250	95	4,000	26
5	159	500	72	5,000	24
10	157	750	59	7,000	21.4
20	153	1,000	51	10,000	19.5
50	142	2,000	35		
100	126	3,000	29		

The mean velocity of flow in an open channel depends mainly on: (1) Slope of water surface; (2) shape of channel, its width, depth, and straightness; (3) roughness of bed and banks; (4) position of mouth of tributary streams; (5) obstructions in channel, such as ice gorges, dams of logs, drift, bowlders, etc.

The formula in general use for computing the discharge of a stream is—

$$Q=AV=AC\sqrt{RS} \qquad (1)$$

In this formula Q=discharge in cubic feet per second, A=area of waterway in square feet, V=mean velocity in feet per second, S=slope of surface, R=hydraulic radius=$\frac{A}{P}$ where P is the wetted perimeter, and $C=\frac{a+\frac{b}{n}+\frac{c}{S}}{1+\left(a+\frac{c}{S}\right)\frac{n}{\sqrt{R}}}$ where a, b, and c are constants and n is the coefficient of roughness of bed. Solving equation 1, we have

$$A=\frac{Q}{V}=\frac{Q}{C\sqrt{RS}} \qquad (2)$$

If a simple method can be found for obtaining the value of V, then the waterway can be found by dividing Q by V.

The following table gives the values of V for slopes varying from 0.1 foot per thousand to 20 feet per thousand, and for values of R from 2 to 25 feet, for the case where $n=0.035$. It covers all cases of flood flow of ordinary streams.

Table for finding the mean velocity in a channel from Kutter's formula when the cofficient of roughness $n=0.035$.

Slope in feet per thousand.	Hydraulic radius.								
	2.	4.	6.	8.	10.	12.	16.	20.	25.
0.1	0.6	1.1	1.5	1.8	2.2	2.4	3.0	3.6	4.1
.2	.9	1.6	2.0	2.5	2.9	3.4	4.2	4.7	5.5
.4	1.3	2.2	2.8	3.6	4.1	4.8	5.7	6.6	7.6
.6	1.6	2.7	3.5	4.3	5.0	5.7	6.9	8.0	9.1
.8	1.8	3.1	4.0	4.9	5.8	6.6	7.9	9.2	10.2
1.0	2.1	3.6	4.6	5.5	6.5	7.4	8.8	10.2	11.6
1.5	2.5	4.3	5.5	6.7	7.9	9.0	10.8	12.5	14.0
2.0	2.9	4.9	6.4	7.8	9.1	10.3	12.3	14.3	16.4
3.0	3.7	6.0	7.8	9.5	11.2	12.8	15.0	17.5	19.8
4.0	4.2	7.0	9.1	10.9	12.8	14.6	17.7	20.2	
6.0	5.0	8.5	10.7	13.7	15.4	17.7	21.5		
8.0	5.8	9.6	12.6	15.6	17.8	20.4			
10.0	6.5	10.7	14.0	17.3	20.0				
15.0	8.0	13.3	17.8	21.0					
20.0	9.3	15.3	20.0						

It can be shown that the hydraulic radius

$$R=\frac{A}{P}=\left(\frac{(I+2d)\,X}{(I+2d)\sqrt{1+X^2}}\right)d \qquad (3)$$

in which I is the bottom width of a trapezoidal section, d is the depth, and X is the slope of the sides. It can be seen from equation (3) that for any given values of d and X, R approaches d as I increases; for the case of floods, therefore, it may be assumed that $R=$ the difference in stage between high and ordinary low water. Any error in the assumption that $R=$range of stage makes R too large, the mean velocity too large, and the computed waterway too small. If desired R can easily be obtained from a measurement of the chosen cross section.

Briefly stated, this method of finding the waterway at a given place on a stream consists in finding the drainage area in square miles above the place under consideration, the greatest change in stage of the stream at this place, and the slope of the surface. By multiplying the drainage area M by q (p. 190), we find Q; dividing Q by

(p. 191), using for R the maximum range of stage, and for S the measured slope of surface of stream, we have the necessary area of the waterway.

The greatest error in the use of this method will result from an incorrect measurement of the slope. The formula calls for slope of surface, and surface slope of a stream is not necessarily the slope of the bed. The slope is not the same at all stages nor always the same for a given stage. If the place under consideration is near the mouth of a large tributary the slope of the main stream will be affected by the stage of the tributary. Overflow and flooding of lowlands is frequently the result of backwater, due to reduction of surface slope. The smaller the slope used the greater will be the computed waterway.

If there is a possibility of the waterway becoming partly clogged with drift, logs, or ice, or its being in the influence of backwater from a tributary, the computed area must be increased by a liberal amount.

The following tables give the maximum rate of flow of streams in various sections of the United States, the date of occurrence, the area of drainage above the station, and the authority. Nearly all these data were obtained with current meter; a few, however, were computed from cross-section and surface-slope measurements.

GENERAL SUMMARY.

Floods on northern streams may result almost entirely from the rapid melting of snow and ice, there being very little rain during the flood.

Floods on northern streams are sometimes produced by ice gorges. The stream may reach a high stage and large areas along the stream be overflowed, while the volume of discharge is comparatively small.

Many of the floods in the western part of the United States are of short duration, produced by heavy storms of short duration, popularly called "cloud-bursts."

The area submerged during a flood depends on slope of stream bed and size of channel. In the lower part of the drainage basin, where the slope is small, the area submerged is larger than in the upper part.

The channel of streams is frequently reduced in width through cities, and overflow results therefrom. The bridges across streams frequently obstruct the waterway to a considerable extent. Too many piers are used, and the pier protection prevents the natural deepening of the channel during floods. The abutments are frequently placed at the low-water line instead of near the high-water line. The control of streams subject to overflow should be in the hands of an engineer or a competent body of men who will prescribe

the proper width of channel and the design of structures over them, and have charge of the work of overflow prevention.

Channel cross-section area should be a function of slope of stream as well as of drainage area and section of country.

Problems of stream control, protection of land along streams, and reclamation of swamp land are rapidly coming to the front in this country, and data bearing on their solution are in demand. In California and Kansas more has recently been done along these lines than in any other State.

The United States Reclamation Service is solving the flood problem in the semiarid region by the construction of reservoirs for the storage of the flood waters for use in irrigation. Destructive floods will eventually be unknown on the streams in this region.

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O

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[Water-Supply Paper No. 147.]

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